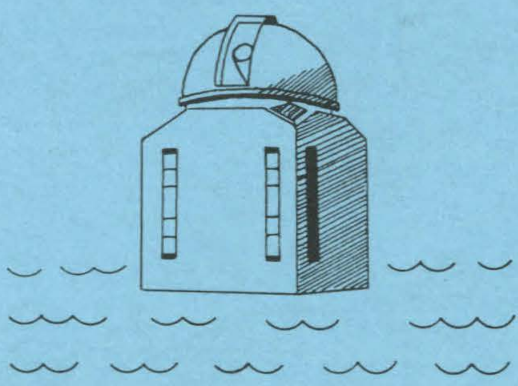
CALIFORNIA INSTITUTE OF TECHNOLOGY

BIG BEAR SOLAR OBSERVATORY

HALE OBSERVATORIES



THE CALTECH VIDEOMAGNETOGRAPH

A Report on its Design and Operation

by

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(1976)

ABSTRACT

The present report describes the installation of the Caltech videomagnetograph at Big Bear Solar Observatory, and its initial operation during 1971-1972.

When fed by a 10" refracting aperture and 1/8 Å λ5324 birefringent filter, the instrument produced an approximately 4x6 arc-minute field of view, within which high resolution (2-3 arc-second) cancellations could be electronically generated and displayed in real time on a video monitor. These cancellations reveal the structure of the photospheric velocities and magnetic fields in time lapse movies. The amount of data which can be created in this manner is impressive. Daily operation between January-September, 1972 produced some 3500' of magnetic movies and 1500' of Doppler footage (35 mm half-frame negatives), representing on the order of 700 and 200 hours of real time, respectively. In addition, a daily survey of active regions yeilded an album of approximately 800 high-resolution H-alpha - magnetic pairs, showing the day-by-day development of more than 60 different solar activity centers.

These data are described and catalogued. Principles of operation, details of construction, troubleshooting, and suggestions for future improvements are also discussed.

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I. INTRODUCTION

The Caltech videomagnetograph was built by Robert Smithson, as a thesis project, in 1969-1970. It is quite possibly the simplest and most effective fully-automatic real-time magnetograph in existence. After a year of testing and debugging from the rooftop of Downs Lab (Smithson, 1972), it was moved, in late 1971, and in a slightly modified form, to its permanent home at the Big Bear Solar Observatory. Capable of measuring line-of-sight magnetic and velocity fields in the sun's photosphere, it generated, during the first year of actual operation, a body of data unequalled by any other instrument in operation at the time.

Both the instrument and the results will be described in the present report.

A. The Instrument

A solar magnetograph is basically nothing more than a device for measuring the polarization of sunlight, or, when velocity in formation is desired, for measuring the difference in intensity between the light levels in opposite wings of a spectral line.

The great variety of magnetographs which are in existence is simply a reflection of the great variety of ways in which that polarization (or intensity) difference can be detected, analyzed, and displayed. In a sense, the videomagnetograph is the product of a conscious effort to combine the more attractive features of a number of earlier schemes, so as to achieve a new and more effective compromise between the conflicting objectives of resolution, sensitivity, and efficiency.

Spectrally pure images, revealing the presence of longitudinal magnetic fields through their Zeeman-induced circular polarizations (and the presence of velocity fields through their Doppler-induced line shifts) are produced by birefringent filters, using techniques developed independently at the Lockheed Solar Observatory in California (Ramsey, 1969), and at CSIRO in Australia (Ramsay et al., 1970). The image is detected photoelectrically and its polarization modulated by an electro-optic crystal (KDP), much as in the classic Babcock magnetograph (Babcock, 1953), but the signal is processed simultaneously over the entire two-dimensional area by using a television camera, recording the oppositely-polarized images, and "subtracting" them in analog form -- an idea which is essentially the electronic adaption of Leighton's (1959) photographic cancellation technique.

B. Objectives

The videomagnetograph was designed as a field instrument (Smithson and Leighton, 1971). By using filters and video technology, it was hoped that a device could be built which would be physically compact enough to adapt to existing telescopes, rugged enough to operate at remote locations, and simple enough to reproduce at reasonable cost. In these respects the videomagnetograph has proved rather successful, yet the compromise which it achieves between resolution and sensitivity is far from perfect. Photographic cancellations, with their shorter exposure times, are still, on occassion, capable of delivering higher resolution, while sophisticated photoelectric systems can achieve sensitivities higher by an order of magnitude ($\sim\frac{1}{2}$-1 gauss at Mount Wilson, for example, compared to ~10-50 gauss for the videomagnetograph). Indeed, among the newer generation of magnetographs, those at Kitt Peak and Sac Peak, though slower and more complicated, seem superior both in resolution and sensitivity; but it is not obvious, even now, that they can equal the videomagnetograph in sheer quantity of output (with as many as 4-5 completed cancellations per minute). This capacity for rapid processing provides a unique observational capability, particularly with regard to the study of rapidly evolving velocity features, and the production of time-lapse magnetic movies.

C. Organization of the Report

This report is organized into several broad categories. Part II describes the hardware of the system. Though fundamentally the same as when first constructed, a number of important changes have been made: the image is modulated by a KDP, rather than by a mechanically-rotated quarter-wave plate; sequencing is controlled by a standard commercial minicomputer, rather than by the original homemade patch-cord controller; most of the interfacing is new; a scheme for generating Doppler cancellations has been developed; a new filter has been constructed; and, finally, the monitor image is photographed on 35 mm (rather than 16 mm) film.

While the basic idea of obtaining magnetic or Doppler information by the subtraction of recorded images is easily understood, the exact details of how this can be accomplished through the coordinated effort of some twenty separate electronic units is, necessarily, rather complex, and will be of interest primarily to those who may wish to use the magnetograph in the future.

Part III is concerned specifically with the initial period of operation at Big Bear, and catalogues all of the data obtained through December of 1972. These data are of two types: "movies" and "surveys". The movie sequences show single regions over periods of several hours (generally at rates of ~ 2 frames per minute); while the surveys indicate their appearance day by day. Each observation is accompanied by simultaneous high-resolution Big Bear filtergrams.

The data are similar to those which could have been obtained at other observatories, but, at least in terms of the coverage of specific regions for this period, they are probably unique. Examples of the magnetic data obtained at Big Bear have been published fairly extensively. See, for example, the articles by Schoolman (1973b), Zirin and Tanaka (1973), Roy and Michalitsanos (1974), Michalitsanos and Kupferman (1974) or Michalitsanos and Bhatnagar (1975). By contrast, very little has been published with regard to the extensive library of active and quiet region Doppler movies.

Appendices I - VI contain practical information regarding the operation of the instrument.

II. INSTRUMENTATION

A. Basic Principles

Because it is at such a great distance from us, it is only natural that most of the information which we possess about the physical state of the solar atmosphere should have been obtained in an indirect, and somewhat devious, manner. The surface magnetic fields, for example, have what, in retrospect, are very obvious and dramatic consequences -- such as sunspots, faculae, coronal loops, and the general iron-filing-like structure of the chromosphere -- but it was not at all obvious to the early observers that the existence of such phenomena implied the existence of magnetic fields, and even today, they remain of limited utility in allowing one to accurately assess the strength or distribution of field lines. The most definite, and the only truly objective, evidence as to the existence of photospheric fields derives from the most subtle of effects.

B. Zeeman Splittings

The spectral lines, formed as the intense thermal radiation from the interior passes through the last relatively cool and extremely tenuous layers of the atmosphere, contain a great wealth of information -- not only about the magnetic fields present in those layers, but also about their mass motions, composition, density, temperature, and turbulence. Naturally these many contributory effects tend to get confused, and disentangling the observations in such a way as to isolate the contribution due to a single cause is seldom simple. However, in the case of magnetic fields, and also of velocities, it is easy enough that a machine such as the videomagnetograph can perform the task (at least to first order) in an automatic and relatively reliable manner.

Magnetic measurements (other than those which are simply guesses based on prior experience) rely, invariably, on the Zeeman splitting of the lines. This effect, arising out of the interaction of the atomic magnetic moment with the external field, is quite small for ordinary field strengths. A 100 gauss field, for example, causes an interaction of only

$$\Delta E \approx \mu_e B \approx 5\mathrm{x}10^{-7}\ \mathrm{eV}$$

compared to typical transition energies of 2-3 eV. Only in sunspots, where field strengths on the order of 3000 gauss are encountered, is the interaction sufficient to split the line into resolvable components.

In general, then, the Zeeman broadening would probably be undetectable were it not for the fact that the oppositely-shifted line components are optically polarized. The presence of a net polarization, particularly a circular one, in the wing of a line is taken to be positive evidence for the existence of a magnetic field, since no other common process is capable of creating such an effect. Magnetographs are thus instruments designed to measure polarization, and not magnetic fields. It is only on the assumption that there is a one-to-one correspondence between fields and polarization that the interpretation of their results in terms of magnetic fields is valid.

For a classical Zeeman triplet, a field perpendicular to the line of sight causes shifted components which are linearly polarized at right angles to the field, leaving a residual, unshifted and parallel-polarized component of sufficient intensity to balance the overall polarization. For a field along the line of sight, there is no unshifted component, and the displaced portions have opposite circular polarizations. In both cases, the overall splitting is given by

$$\Delta\lambda(\text{Å}) = 9.4\text{x}10^{-13}\, g\lambda^2(\text{Å})\, B(\text{gauss})$$

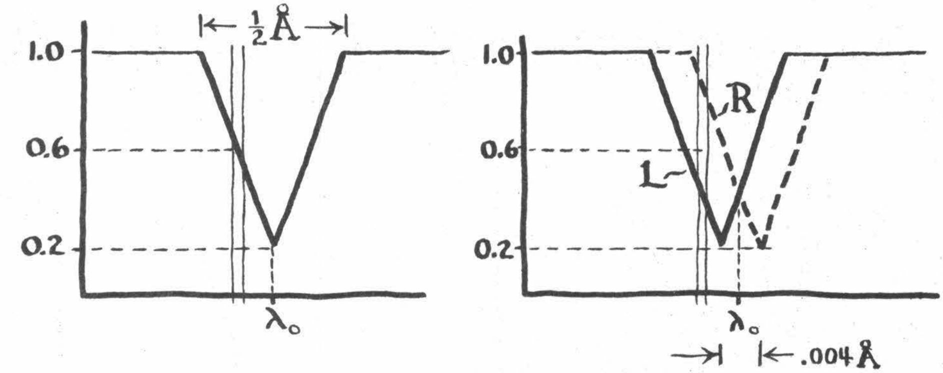
each shifted component moving by half of this amount. For reasons which will be dealt with later, the transverse field is usually ignored, the measurements referring exclusively to the line-of-sight component. These reasons are observational, and the neglect of the transverse component is not meant to imply that it is less important physically.

Figure 1: The magnetic signal

A magnetic signal may be obtained by comparing the intensities of left- and right-hand circularly polarized light as seen in a single bandpass in the wing of a magnetically sensitive line. For weak splittings the line profile may be adequately approximated by a triangular shape representing the slope of the wings. The largest percentage signal is obtained by operating close to the line center, where the ambient light level is low. For stronger fields, the true line profile should be used.

Note that in part (A) the magnitude of the magnetic splitting is greatly exaggerated relative to the width of the line.

A. Weak fields (100 gauss)



$$\frac{\Delta I_L}{I_L} = \frac{\Delta I_R}{I_R} = \left(\frac{0.8\, I_o}{.25\, I_o}\right) \times \frac{(\pm .002\, Å)}{(0.6\, I_o)} = \pm 1.07\%$$

B. Strong fields (3000 gauss)

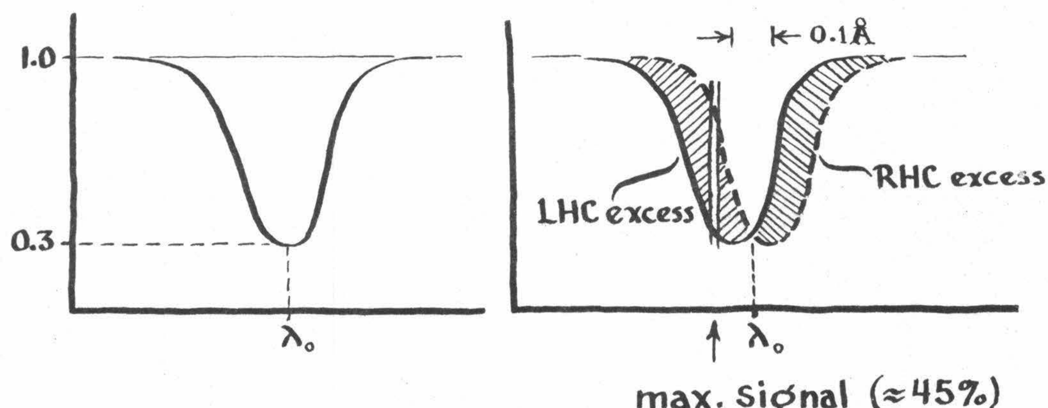


Figure 1.

Although not large, the expected magnetic signal is large enough to be detected by relatively straight-forward means. As shown in Figure 1a, the signal is derived basically, by comparing the relative intensities of right- and left-handed light at some point in one wing of the spectral line, say at its midpoint. To get an idea of its size, consider the specific example of the Fe I line at 5324 Å, g = 3/2. The shape of the line can be approximated by a triangle with a width at the top of about 1/2 Å, and extending at the center to a depth of about 0.2 of the continuum intensity. For a shift of .002 Å, corresponding to a line-of-sight field of 100 gauss, the intensity in the wing will change by about .006 of the continuum (one polarization increasing and the other decreasing by this amount). When compared to the background intensity of 0.6 I_o in each channel, this represents a 1% signal.

The exact size of the signal depends, of course, both on the slope of the line and on the operating point. For the triangular profile which we have been assuming, the fractional signal could clearly be made greater by operating closer to the center of the line, where the background intensity would be lower. In a more realistic line profile, however, that advantage would be less pronounced, since the effect of the lowered background would tend to be offset by the shallower slope of the profile close to the core.

The maximum signal that can be obtained is also of some interest, since it governs the ease with which very strong fields, such as those in sunspots, can be seen. It is also very easy to estimate since it is essentially nothing more than the depth of the line. A 3000 gauss field would separate the two circular components of λ5324 by about 0.1 Å, marginally sufficient to split the line into resolvable components. As shown in Figure 1b, the maximum difference between left- and right-handed intensities is found close to the point to which the core of the line is moved by the splitting, or about 0.05 Å into the wing for our example. For λ5324, this maximum signal is about 45% (each component changing by this amount from its undisturbed intensity). Operating any closer to the core of the line would introduce a saturation effect, causing the signal to actually appear weaker for very strong fields than for those of moderate strength.

The estimate of about 1% signal per 100 gauss is roughly valid for most favorable lines in this wavelength range. Significant improvement can, however, be achieved by using lines farther to the red, if the detector will permit. Although the lines tend to be broader and the filters less sharp, these effects are more than offset by the λ^2 factor in the splitting formula. Unfortunately, the videomagnetograph is limited in this respect by the spectral sensitivity of the Plumbicon television camera, which peaks in the green and cannot function well on the relatively low light level available at longer wavelengths.

C. Doppler Shifts

Like the magnetic fields, surface velocities are also detected indirectly through their influences on the spectral lines. Just as a line-of-sight magnetic field was the only mechanism capable of introducing circular polarization into the wing of the line, a line-of-sight velocity is the only mechanism capable of altering the overall wavelength, and the presence of such a Doppler shift can be taken as positive proof for the existence of a velocity.

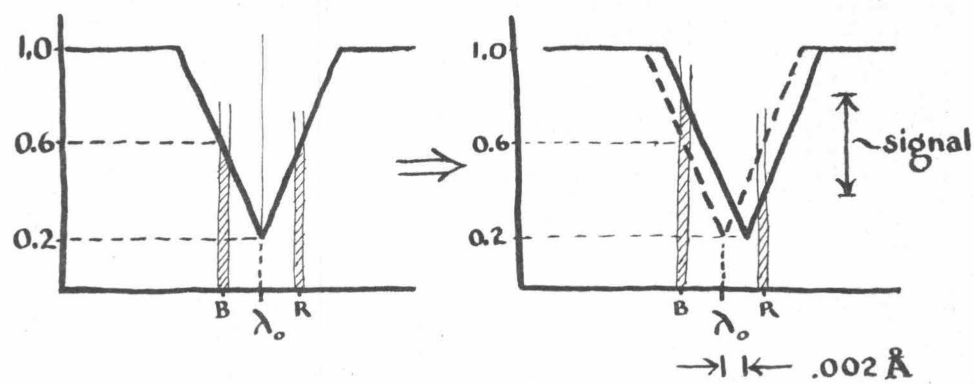
The scheme generally used for detecting these shifts is similar to that used for detecting the Zeeman splittings, except that this time, instead of comparing the intensities in two oppositely-polarized channels in one wing of the line, one compares the intensities in two unpolarized channels in opposite wings of the line. Figure 2 illustrates this process schematically. In the absence of any Doppler displacement, the intensities in the red and blue wings would balance. If, however, the line-forming material were moving, say, toward the observer at 0.1 km/sec, then the line-profile would be shifted by about .002 Å to the blue (the same shift that was produced by the 100 gauss magnetic field). This

Figure 2: The Doppler Signal

The Doppler signal is obtained by comparing the intensity of light in two bandpasses at equal distance from the core of the undisturbed line. The background light level from which the signal must be extracted is the sum of the levels in the two channels. Ideally, a non-magnetic line should be used.

Doppler mode:

normal: shifted (0.1 km/sec):



$$\frac{\Delta I}{I} = \frac{I_R - I_B}{I_R + I_B} = \frac{2 \times \left(\frac{0.8 I_o}{0.25 Å}\right) \times (.002 Å)}{2 \times 0.6 I_o} = 1.07\%$$

Figure 2.

causes the intensity in the red channel to increase by about .005 of the continuum level, while the intensity in the blue channel would fall by the same factor. Compared to the normal background intensity, this change would, once again, correspond to a signal of about 1%.

Although larger velocities are encountered, this is a reasonably typical one for the photosphere. The random thermal motions and fine-scale turbulence which create line widths of about 0.1 Å at 5000 Å imply the existence of at least some velocities on the order of 2×10^{-5} of the velocity of light, or about 6 km/sec. This agrees well with what one would expect for a 5000° K plasma. The sound speed should represent a kind of upper limit for the convective motions in which we are interested. Assuming that one works far enough out in the wings to avoid serious saturation effects, this could lead to a maximum Doppler signal of about 60%. The fact that velocities of almost this size are actually encountered is clear from the distinct "wiggly-line" structure of high resolution spectra. These wiggles would not be noticeable unless the Doppler shifts were roughly comparable with the line-width.

The displacements caused by the sun's apparent 27 day rotation turn out to be comparable with the other Doppler shifts. Because of this rotation, the East limb appears constantly to be approaching us at a velocity of about .75

km/sec, while the West limb appears to be receding at the same speed. In practice, then, a comparison of the shifts observed at the two limbs provides a useful calibration for the relative magnitude of the velocities observed elsewhere.

As with the magnetic fields, our measurements once again deal only with the line-of-sight component. This time, however, the limitation is fundamental, and not merely a matter of observational difficulty: the line-shifts caused by transverse velocities are a second order relativistic effect, much too small to be detected by any ordinary means.

We have seen, then, that the sun provides us with an unambiguous way of determining the presence of either longitudinal magnetic or velocity fields in the photospheric layers. In the first instance, one examines the difference between right- and left-handed intensities in one wing of the line; in the other, one compares intensities on either side of the line. Of course the detection and interpretation of such anomalies is subject to certain possible errors. These errors tend to vary with the methods employed, and so we shall now consider a few of those many methods, which range everywhere from direct visual observation to point-by-point photoelectric analysis. Of these, the videomagnetograph is most nearly patterned after the photographic cancellation scheme developed by Leighton (1959).

D. Photographic Cancellations

The photographic cancellation technique relies on the idea, developed in the previous sections, that the presence, and, indeed, the magnitude, of surface magnetic and velocity fields can be inferred by comparing the intensities of light in two spectral channels -- either of opposite circular polarization or in opposite wings of a line.

In contrast to earlier methods which had employed sensitive photoelectric detectors to analyze the light at single points in the image, the Leighton technique uses photographic plates to record the intensity over an extended two-dimensional area. The magnetograms and Dopplergrams are then produced directly from these two dimensional records. In this way, the spatial resolution is determined solely by the quality of the original images, and is not limited by the entrance aperture of some bulky detector which must be physically moved from point to point in the image.

Many variations on the basic photographic cancellation technique have evolved. The original work at Mount Wilson (Leighton, 1959; Leighton, Noyes, and Simon, 1962) employed a large spectroheliograph to produce solar images in a variety of lines. Subsequent forms have used optical filters in place of the spectroheliograph (Ramsey, 1969), and film in place of the glass plates (Title, 1965).

Whatever method is chosen, one picture will be exposed in each of the two spectral channels. Thus, when making a Zeeman cancellation, one photograph would show the intensity of right-handed photons in the wing of a favorable spectral line, while the other would show the intensity of left-handed photons in the same wing. For a Doppler cancellation, on the other hand, one photograph would show the (unpolarized) intensity in the red wing, while the other would show the (unpolarized) intensity in the blue wing. It is generally possible, by means of beam splitters, to obtain these two images simultaneously, but it is not necessary, and is not always done.

Since the variations in intensity due to Zeeman splittings and Doppler shifts are small, and tend to be lost in the background variations (due, for instance, to temperature fluctuations), their presence cannot usually be deduced by simply looking at either of the two original, uncancelled plates. The contrast between the brightness of a granule and its surrounding lanes, for example, or of the photospheric network relative to the ordinary granulation, is on the order of 10%; quite comparable with the signal caused by a kilometer per second velocity or a thousand gauss field. To isolate the part of the intensity fluctuations due to these fields, it is therefore necessary to compare the two photographs very carefully, picking out just those points at which the recorded intensities differ, and ignoring the others. To do this by actual visual comparison would, however, be extremely laborious. What is needed is a procedure for "subtracting" the two pictures: that is, for displaying only the differences, and for doing so automatically.

The method suggested and developed by Leighton was this: if any photograph is superimposed upon a negative of itself, then the darker-than-average features on the original will overlie corresponding lighter-than-average areas on the negative. If the contrast of the negative is properly adjusted ($\gamma = 1$), and if the densities lie within the linear range of the emulsion, then the resulting composite will be a dense, but uniform, gray. If, however, the negative is from a similar, but slightly different scene, then only those areas in which the two photographs are the same will cancel, while the places where they differ will stand out as lighter-than-average or darker-than-average features against this gray background (whether they show dark or light is determined by which of the two original photographs exhibit the highest density).

Now while it is obvious that this procedure will indeed isolate the differences between the plates, it is not so clear that the response will be linear, nor that equal apparent "signals" will necessarily represent equal differences in the original. In fact, however, photographic emulsions

<u>Figure 3</u>: <u>The photographic cancellation technique</u>

Scenes "A" and "B" differ only in the placement of the small circle. By superimposing a positive of one on top of a negative of the other, these differences can be seen as a positive and negative signal against a dense gray background.

A similar effect can be achieved electronically by subtracting the video analogs of the two scenes. In that case, however, the background gray level is arbitrarily adjustable.

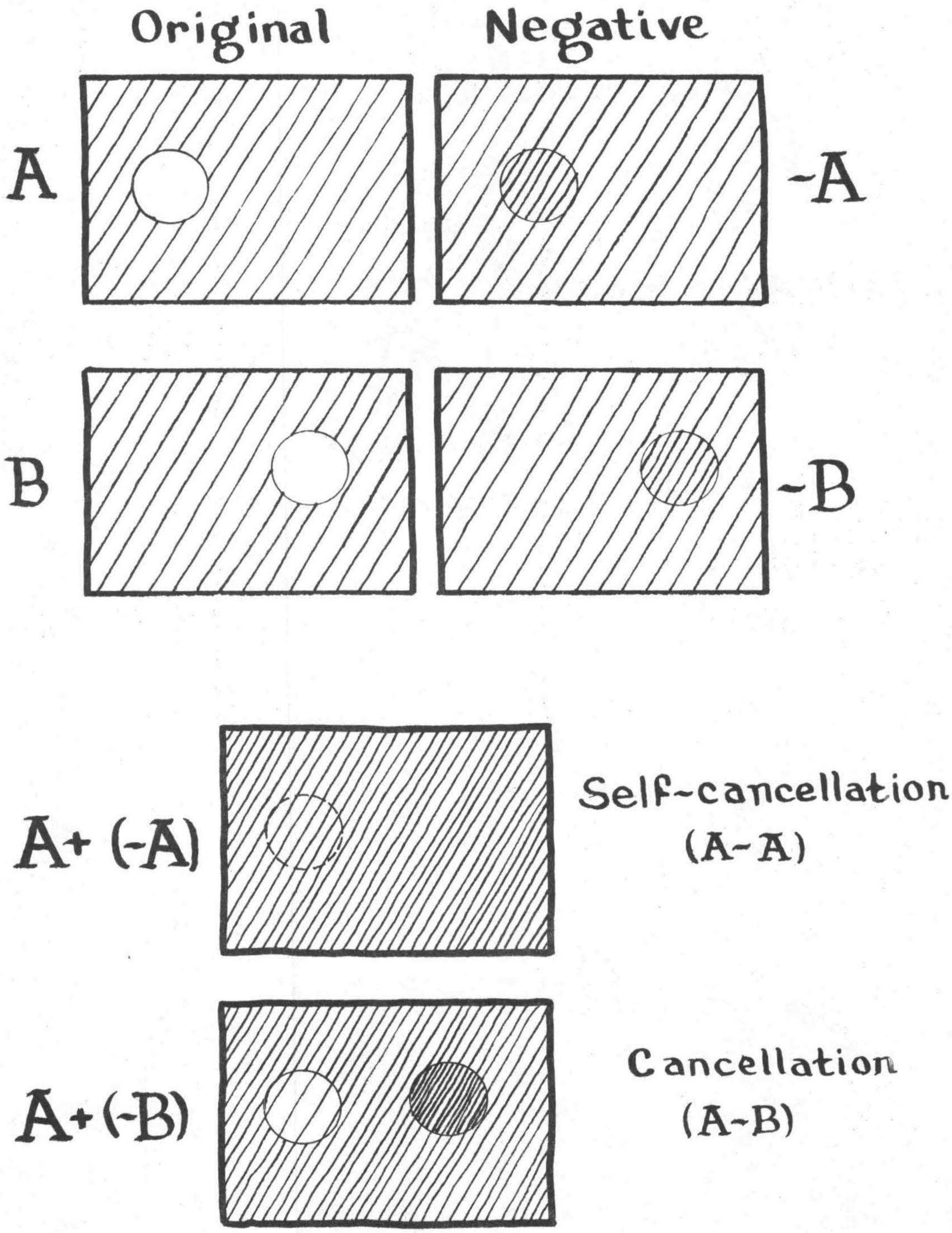

Original
Negative
A
-A
B
-B
A+ (-A)
Self-cancellation
(A-A)
A+ (-B)
Cancellation
(A-B)

Figure 3.

tend to have a more-or less logarithmic response, and, because of that, these conditions are met. That is, equal percentage signals (caused by a particular field strength of a particular velocity) will tend to create equal density variations on the cancellation, even though the background intensity may vary from one point to another.

In spite of its elegance, the photographic cancellation technique has its problems. In particular, the sensitivity of the method is limited by the relatively small range of densities that can be used. As a result, it would seem that the technique is actually little more sensitive than the eye in detecting differences between the photographs (although the display is far more convenient) -- corresponding, perhaps, to threshold signals of a few percent in the live images. This relatively low sensitivity, together with the difficulty of controlling the darkroom procedure accurately enough to maintain the $\gamma = 1$ condition, and of properly registering and reproducing the plates, has tended to discourage extensive use of the method.

The development of the videomagnetograph represents an attempt to improve upon, and further automate the cancellation procedure -- the basic idea being to eliminate the more difficult steps by using a video recorder instead of film. In this way, the recorded images can be subtracted electronically, in real time, and with no darkroom procedure at all.

In addition, the video subtraction system offers the potential of a somewhat higher sensitivity.

E. The Videomagnetograph

The videomagnetograph consists, in essence, of a narrow-bandpass optical filter, which isolates the wings of a chosen Zeeman-sensitive line; a television camera, which converts the live image into an electrical signal; a video recorder, which records that signal; a "multiplexing" circuit, which subtracts the recorded images; and a monitor, which displays the result. In addition, the control of all these parts requires the services of a small computer, and the presence of a considerable array of electronic interfacing.

The decision to use a filter, rather than a spectroheliograph, for producing the solar images was based primarily upon considerations of efficiency. The spectroheliograph is extremely flexible, in the sense that it allows one to use virtually any line, varying the wavelength and bandpass at will; but it is also extremely wasteful, in the sense that most of the available light is simply reflected off the entrance slit and lost. It is also rather difficult to adapt to the needs of the television camera, which, in ordinary operation, would like to have its entire photo-sensitive surface continuously illuminated. In as much as there was no particular plan to use the system on more than one line

Figure 4: The videomagnetograph

Sunlight entering from the left is imaged in such a fashion as to form a focused picture on the faceplate of the television camera. By modulating the KDP, left- and right-hand circularly polarized frames can be recorded alternately on the disc, and then played back through a multiplexing circuit so as to form the final cancellation, which is displayed on an ordinary video monitor.

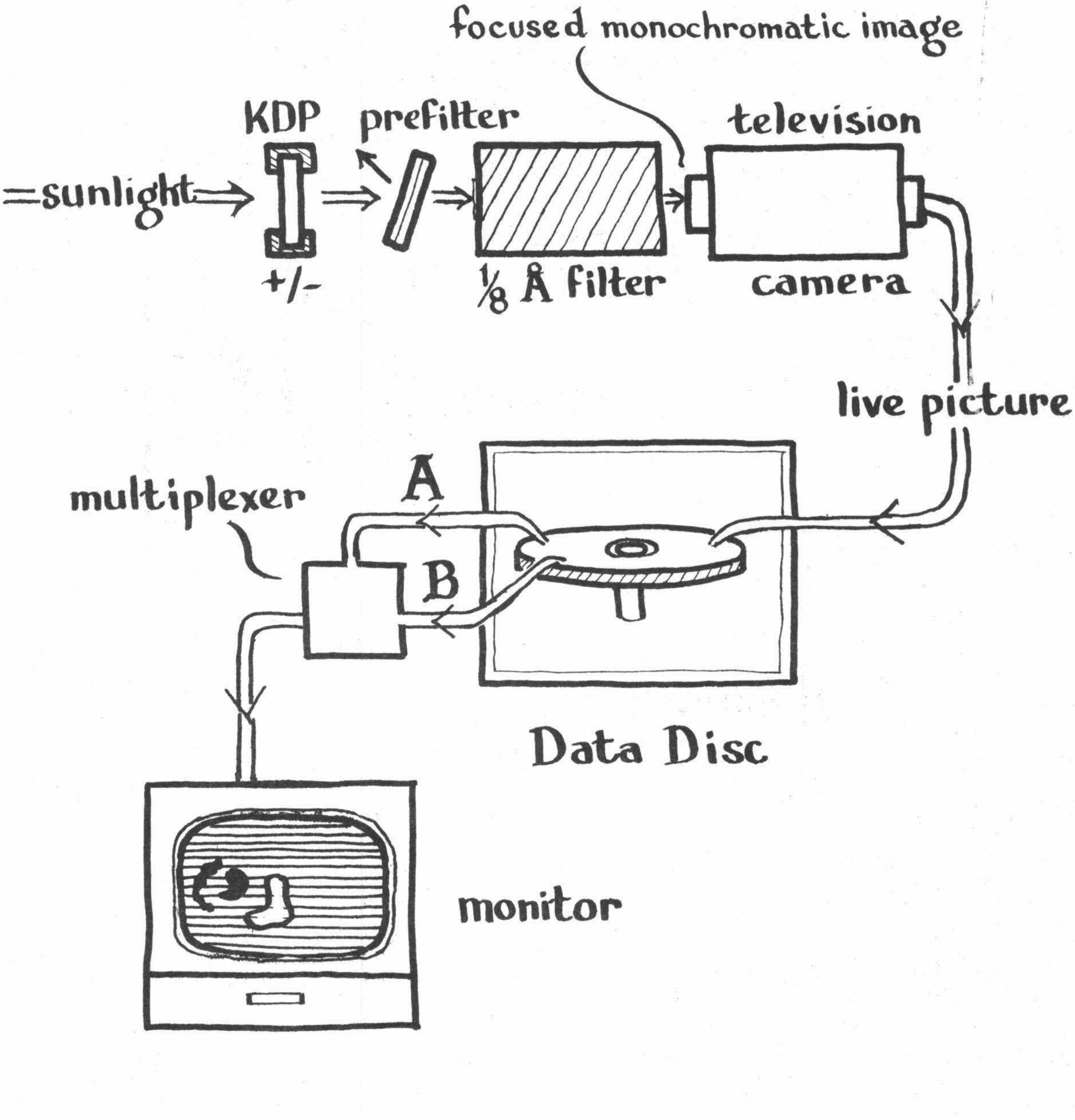

focused monochromatic image
KDP
prefilter
television
=sunlight
+/-
1/8 Å filter
camera
live picture
multiplexer
A
B
Data Disc
monitor

Figure 4.

(it was intended for routine magnetic survey work) the choice of the filter option seemed obvious. The choice was also encouraged by the success of the filter-photographic magnetograph developed at Lockheed Solar Observatory (Ramsey, 1969). Indeed, the original $\lambda5324$ filter was loaned to us by them.

In the original videomagnetograph, as in the Lockheed version, the switching of polarizations was accomplished by rotating a mica quarter-wave plate in the beam ahead of the filter. This technique was soon improved, however, by the introduction of an electro-optic crystal (KDP: potassium dihydrogen phosphate). The KDP is an artificially-grown crystal which acts as a waveplate of variable retardation when a high voltage is applied to its transparent electrodes. The use of such crystals in connection with solar work dates back to the original Babcock magnetograph (Babcock, 1953), although in our case the crystal has a large ($\approx$1") clear aperture of high optical quality. The use of the KDP not only speeds up the operation, but also avoids the problem of geometric distortions caused by the rotating mica. In principle, the KDP can be switched at megahertz frequencies, but in practice, at least 1/30 second must be allowed after each reversal so that the television camera can go through a complete sweep cycle, and thereby erase the image formed with the previous polarity.

The main new problem associated with the videomagnetograph is the inherent noisiness of the live pictures. The typical $\sim 1\%$ background noise is higher than that which could be obtained with slow, fine-grained films, and comparable with the sort of weak signals which one would like to be able to detect. On the other hand, the video "exposure time" of 1/30 second is faster than would be used photographically (with the fine-grained films), so that most of the loss can be made back, without seriously increasing the overall integration time, by averaging together a series of the relatively noisy "raw" cancellations.

The modulated live pictures are recorded on a commercial video disc recorder (Data Disc) for subsequent cancellation, and the averaging is accomplished by playing back pairs of recorded differences and then re-recording their sum elsewhere on the Disc. To avoid being swamped by additional noise added in the recording and playback processes, the initial difference (which would ordinarily be a very small amplitude signal) is enhanced in gain by about a factor of 10. Thus the recording noise ($\sim 1\%$) becomes comparable with 0.1%, rather than 1% differences in the live pictures. Since this is small, the noisiness of the cancellations is therefore improved approximately according to the square root of the number of frames averaged together. Optimum results have been obtained when averaging together about

50-100 live picture pairs, corresponding to a theoretical threshold sensitivity of about 0.1% (in the live pictures, or about 1% noise on the final recorded magnetogram -- roughly, the minimum noise that can be achieved in a recorded picture).

According to the earlier estimates, this sensitivity would be sufficient to detect magnetic fields of about 10 gauss and velocities as small as 0.01 km/sec. In practice, however, one can anticipate a number of sources of error which would tend to make the sensitivity considerably less spectacular. In particular, the live pictures (particularly for Doppler cancellations) are often noisier than 1% due to a marginal light level, the cancellations are even noisier due to seeing fluctuations between frames, and the transfer noise (particularly in the initial pre-cancellation phase) is not entirely negligible. In addition to these electronic problems, the magnitude of the signal is also subject to potential inadequacies in the optical system. In particular, problems associated with instrumental polarization, scattered light, and imperfect spectral resolution would all tend to degrade the signal. The spatial resolution of the system will also affect the apparent signal strength. If the fields or velocities on the sun are concentrated into areas smaller than that resolved by the cancellations, one will see only a sort of smeared-out and watered-down version of the true signal strength.

As an example of these losses, consider the effect caused by the finite spectral resolution of the filter. The earlier estimates of signal strength assumed that the line was perfectly resolved, so that the true profile, as plotted, for example, in the Utrecht Atlas, could be used in calculating the sensitivity. The actual signal, however, comes not from this ideal line shape, but rather from the effective profile as seen by the filter.

The use of, say, a 1/8 Å filter to observe a 1/4 Å wide line (typical of most of the potentially useful photospheric lines) would significantly reduce the signal estimate. Assuming that the widths add roughly as the sum of squares, the filter would effectively increase the width and reduce the depth of the line by about 10%. This alone would be sufficient to reduce the signal by some 20%, but the effect is actually even worse since the filter not only washes out the slope of the wing one wants to use, but also lets through parasitic light originating in the opposite wing and carrying the opposite signal. For a 1/4 Å filter, the loss in signal would be at least a factor of 3.

Considering that there are four or five such sources of trouble which each might reduce the signal by, say, 10-20%, it would not be surprising to find that the earlier estimates were in error by a factor of 3 or 4. Thus for the videomagnetograph the actual threshold magnetic intensity might be more like 30-40 gauss and the threshold velocity as high as 0.05 km/sec.

F. Birefringent Filters

As we have just seen, rather narrow filters are required in order to adequately resolve the wings of spectral lines. On the other hand, excessively narrow filters are not desirable. The sensitivity of the magnetograph is mainly determined by the effective slope which it sees in the wings of the line, and once the wing has been resolved, a still narrower filter will not significantly improve it. It will, however, reduce the light level -- and the reduction may be quite dramatic, since each reduction in bandpass involves adding more elements and more polaroids to the filter. The losses due to scattering, absorption, and other imperfections in the polaroids alone will lower the light level significantly, and this is in addition to the basic loss caused by the reduced spectral window. Such a sacrifice is senseless if it does not provide an increase in sensitivity, and about the only way in which the very narrow filter could help to increase the sensitivity would be by allowing one to operate closer to the core of the line where the lower background light level would make the percentage signal seem greater -- but that gain is likely to be illusory, since the transmission would probably be so poor that operation that close to the core would not be practical. As a rule of thumb, optimum performance is generally achieved when the filter bandpass just matches the width of the line wing (i.e., about half the width of the line).

The construction of a 1/8 Å optical filter is no easy matter. In the visible, combinations of colored glass and vacuum-deposited interference filters can get down to about 10 Å, but the final filtration must usually come in the form of high-quality birefringent elements.

The details of such birefringent filters are discussed elsewhere (Lyot, 1933; Evans, 1949; and also in Appendix I). In essence they consist of a series of calcite blocks sandwiched between crossed polaroids, each block being half the length of the preceding one. The individual elements have cosine-squared transmission patterns of varying "wavelength", the longest elements giving the sharpest and most closely spaced peaks. Each pattern can be slid in wavelength by rotating a polaroid. Normally all of the elements are tuned so as to pass one chosen line, and, if the lengths are properly chosen, one will find that at the same time most of the sidebands are suppressed within a limited range around the central peak. Wavelengths still farther from the line are eliminated by the prefilter.

G. Double-Bandpass Filters and Doppler Cancellations

In the filters used with the videomagnetograph, all elements except for the first one are pre-tuned in this fashion. The first element, though, is left so that it may be tuned externally by rotating a polaroid in the beam ahead of the filter. If the filter is a 1/8 Å one, this means that there will be a fixed 1/4 Å envelope (due to the rest of the filter) against which the cosine-squared transmission pattern of the 1/8 Å element may be moved. A 180° rotation of the entrance polaroid causes this pattern to go through a complete cycle, returning to its original form. A 90° rotation turns it into a complementary form -- having peaks where it previously had minima, and minima where it previously had peaks.

As shown in Figure 5 (see also, Figure 3 of Appendix I), there are two orthogonal entrance polarizations which will give mirror peaks displaced slightly in wavelength. If the overall bandpass is centered on a line then these peaks will be at 1/16 Å into the wings (for a 1/8 Å filter).

The ability to switch between separate bandpasses is essential for Doppler cancellations, and turns out to be useful in the Zeeman mode as well. The actual rotation of a polaroid in the beam is undesirable, however, since it will tend to distort the image and make cancellation difficult. Fortunately, the switching can be accomplished electronically.

As shown in Figure 5, if the KDP is preceded by a circular polarizer (consisting of a polaroid plus quarter-wave plate) then the KDP, also acting as a quarter-wave plate will convert that circular polarization back into a linear form at 45° to the KDP axes, but the particular angle can be switched by changing the sign of the voltage (equivalent to rotating a mica quarter-wave plate by 90°).

If the KDP is oriented so that these two directions correspond to the two mirror-image bandpasses, and if the filter is centered on a line, then for one polarity, only those photons whose wavelengths happen to lie in the red wing will get through, while for the other polarity, only those photons whose wavelengths happen to lie in the blue wing will get through. This is precisely the condition needed in order to perform Doppler cancellations.

H. Zeeman Cancellations

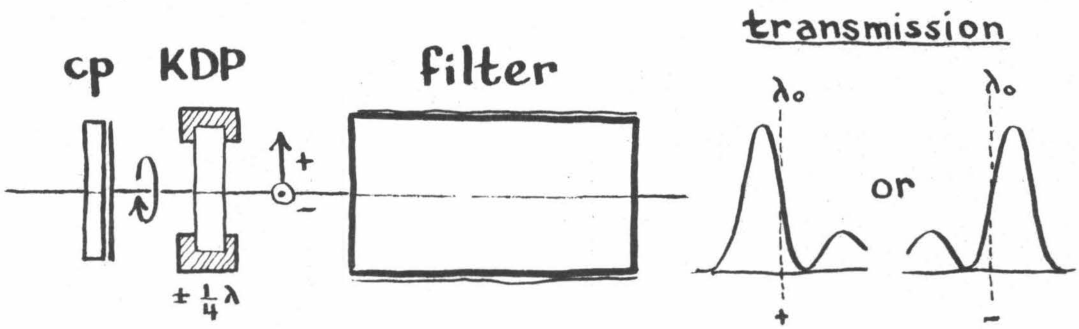
A number of schemes for performing Zeeman cancellations, that exploit the properties of double bandpass filters, have been suggested (Steel *et al.*, 1961; Öhman, 1965), but the particular one used in connection with the videomagnetograph was suggested and developed independently by Ramsey (1971).

Surprisingly, one can change from the Doppler to the Zeeman mode simply by removing the circular polarizer (see Figure 5). In such a configuration, the sunlight enters the

Figure 5: The magnetograph modes

The magnetograph filter is so constructed that two orthogonal entrance polarizations will be transmitted in the wings of the main filter bandpass. In the Doppler mode, the system is fed by circularly polarized light. The KDP, acting as a plus or minus quarter-wave plate converts this light, alternately, into the two linear polarizations. In the magnetic mode, the circular polarization is supplied directly by the Zeeman effect. In both figures, the KDP and filter axes are at 45° to the plane of the paper. The two modes differ only by the addition of the initial circular polarizer.

Doppler Mode:



(the KDP axes are at 45° to the plane of the paper)

Zeeman Mode:

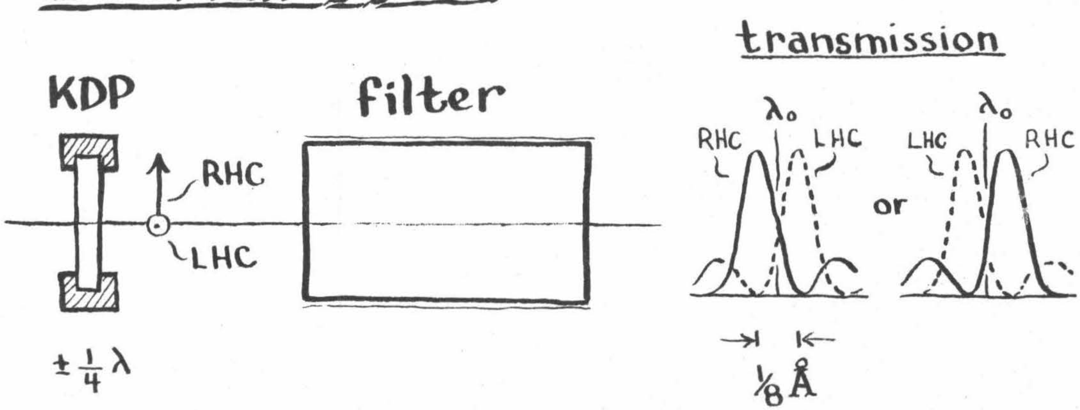


Figure 5.

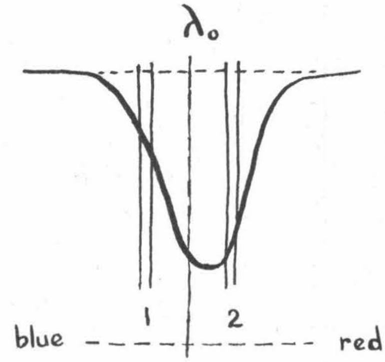
Figure 6: Explanation of double-bandpass modes

The Doppler and magnetic signals are both obtained by subtracting the image obtained with the KDP in its positive state from that obtained when the KDP is in its negative state.

In the Doppler mode, the operation is quite straight forward, the signal consisting simply of (red wing) minus (blue wing). Rising elements give a lighter-than-average result, while falling elements give a darker-than-average one.

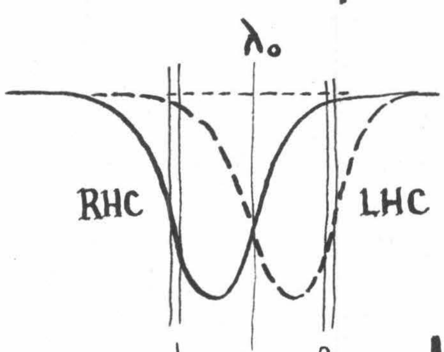
In the magnetic mode, the signal consists of (right-handed light in the red wing plus left-handed light in the blue wing) minus (left-handed light in the red wing plus right-handed light in the blue wing). As indicated by the chart, positive fields give a lighter-than-average result, while negative fields give a darker than average one. The signal is the same as would be obtained with a single bandpass in either wing, but at twice the light level.

Doppler Shift



	(KDP+) Red wing	(KDP-) Blue wing
rising element	bright	dark
falling element	dark	bright

Zeeman Splitting



	Red wing		Blue wing	
	RHC	LHC	RHC	LHC
positive field	bright	dark	dark	bright
negative field	dark	bright	bright	dark
	(+)	(−)	(−)	(+)

Figure 6.

magnetograph optics directly through the KDP, both circular polarizations being admitted simultaneously and continuously. The magnetic signal, which comes from the difference in intensity between the right- and left-handed images would be lost at this point were it not for the fact that the two circular polarizations are transmitted in opposite wings of the line. That is, for one polarity of the KDP, a right-handed photon must lie in the red wing while a left-handed photon must lie in the blue wing in order to get through the filter-KDP combination; for the opposite KDP polarity, these associations are reversed.

The table given in Figure 6 shows how the magnetic signal manages to survive. When a Zeeman splitting causes the red wing to show an excess of right-handed photons, the blue wing will simultaneously show an excess of left-handed photons. Thus at a point where the right-handed photons, transmitted in the red wing, make a brighter-than-average contribution to the final image, the left-handed photons, transmitted in the blue wing, will also do so. Similarly, an area which would be dark in the one wing will be doubly dark on the composite image delivered by the filter.

This is not meant to imply that the "contrast" is any greater than would be obtained with a comparable single band-pass filter operating at the same point in the line profile. The signal-to-noise is exactly the same. Rather, it is just the general light level which is enhanced by a factor of two: in the single bandpass mode, half of the available light is rejected by the initial polaroid; in the double bandpass mode, all of the available light is used. Although a factor of two may not sound very important when dealing with a target as bright as the sun, it is, since, as we shall see, the number of photons available in the final filtered images delivered to the magnetograph is just barely acceptable for a successful operation.

In return for the increased efficiency of the double-bandpass mode, one must sacrifice one's ability to vary the position of the bandpass in the wings of the line: the position is completely determined by the characteristics of the filter, which must in turn be compatible with the width of the line. The double bandpass profile is also somewhat less clean than that of a single bandpass filter, what with its small unwanted sidelobes in the opposite wing of the line. Neither of these disadvantages seems to be serious in practice, however, or at least they are greatly out-weighed by the advantages associated with the improved light level. All filters tried have been found to function significantly better in the double bandpass mode than in the single bandpass one.

In addition to this improvement in signal, the double bandpass mode also has the advantage of allowing one to relatively easily optimize the operating temperature of the filter (which determines whether or not the filter will be properly centered on the desired spectral line). Since the bandpass shifts by about a half an Angstrom per degree (moving to the blue as the temperature rises) small errors (caused by variations in room temperature, for instance, or by sunlight falling on the filter can seriously degrade the signal. In the single bandpass mode one can never be entirely sure whether or not the temperature should be re-adjusted, and if so, in which direction. In the double bandpass mode, all one has to do is to re-insert the circular polarizer (converting the filter back to the Doppler mode) and check to see whether the intensities in the two channels are balanced.

I. Light Level and Image Size

Because of losses due to scattering and absorption in the polaroids, the efficiency of a birefringent filter, although high compared to that of a spectroheliograph, is not perfect. In fact, a 1/8 Å filter which transmits even a few percent of the central wavelength is generally considered to be quite good. When one combines the effect of this relatively poor transmission with that of the narrow portion of the spectrum being used, it turns out that moderately large apertures are required if one wants to gather enough light to be able to extract statistically significant difference signals in a reasonable amount of time. Although it might seem that the limitations imposed by a small aperture could be overcome simply by extending the integration time, this approach is unfeasable, both because things change on the sun (particularly velocities), and because the averaged effects of atmospheric seeing would seriously degrade the final results.

The Plumbicon camera (Philips type XQ1023R) used with the videomagnetograph, a relatively sensitive detector, requires, in the green, an incident intensity of about 1 $\mu W/cm^2$ in order to produce its optimum live image. At this light level, about half of the noisiness in the live pictures comes from statistical fluctuations, and half from the electronics ($\sim 10^6$ photons being collected per resolution element per frame). Considering that the solar spectral irradiance at 5324 Å is only about 15 $\mu W/cm^2$-Å (Allen, 1973; §89), and that this is reduced to less than 0.05 $\mu W/cm^2$ when corrected for the filter transmission (certainly no better than 5%), the spectral window (1/8 Å), and the line absorption (an additional factor of 2 or so), it becomes clear that one must use the telescope not only to focus the image, but also to concentrate the light. Yet the effort to make high resolution magnetograms cannot be totally abandoned to the quest for higher light levels. A compromise must be reached in which one combines an adequate image size with an adequate level of illumination. The details of how this compromise is reached are discussed in Appendix II, but a few of the more important points are worth mentioning here.

As explained in Section E, a minimum of 50 frames must be averaged together in order to produce sufficiently sensitive cancellations for magnetic work. These pictures require at least 2-3 seconds to acquire (see Appendix IV). Hence, the spatial resolution of the cancellations will always be limited by the effects of seeing averaged over this length of time. Even at Big Bear, features smaller than 1-2" can seldom, if ever, be seen on a 2-3 second exposure.

It is, however, a high enough resolution that areas no more than about 4'x6' in size can be properly displayed on the television monitor. This optimum display scale is the one normally used with the magnetograph. A larger scale display, showing a smaller portion of the surface, would sacrifice needed light and yet show little, if any, additional detail. A smaller scale one, showing a larger portion of the surface, would gain light, but then the resolution would be limited by the number of lines on the monitor. At the optimum 4'x6' scale, the solar disk measures about 10 cm in diameter at the image plane (actually, only the small potion of the image destined to be displayed on the monitor is actually formed, and the rest is removed by means of a reflecting field stop placed at the prime focus).

With present filters, the smallest entrance aperture sufficient to illuminate such an image is 10″ (25.4 cm), giving something like 0.2-0.3 $\mu W/cm^2$ on the camera faceplate. This is the only size lens that has been used at Big Bear. During the construction of the magnetograph at Caltech, however, a 6″ lens was available. With the smaller lens, an adequate light level could be obtained only by using an $\sim 7' \times 10'$ field of view, and the resolution suffered accordingly.

Larger apertures could improve the light level, but only at the expense of a more rapidly converging beam, and the present f/35-40 beam already seems marginal for Doppler work (judging by the field non-uniformities). To attain the optimum 1 $\mu W/cm^2$ light level would (with present filters and the $4' \times 6'$ format) require doubling the entrance aperture, increasing the speed to f/15-20, too fast, probably, even for magnetic work.

Future improvements in the videomagnetograph, would, therefore, seem to lie more in the realm of better filters than of larger telescopes.

J. Electronic Processing

The production of high-quality spectrally-pure live images is only part of the overall problem. In order to produce Doppler- or magnetograms it is necessary not only to have the images, but also to be able to record and cancel them. Our use of the Data Disc in this regard has already been touched upon in Section E, and will be considered at greater length in Appendixes III and IV. Nonetheless, some additional background is necessary at this point if one is to understand the description of the processing technique.

Each Data Disc is to some extent a unique device, the exact details of its construction being tailored towards its intended application. Primarily, the variations between units are with respect to the kind and number of recording "heads". Ours has four. Two of these (Heads 3 and 4) are mechanically fixed, and capable of storing only one video frame at a time. The other two (Heads 1 and 2) are mounted on runners, and can, by means of electronic stepping motors, be moved in or out to any one of about 150 discrete positions. At each of these a picture can be stored.

The quality of recordings made on the fixed heads is, however, somewhat higher than that achieved with the moving ones, and hence in making magnetograms, it is desirable to extract the primary difference signal from pictures recorded on the <u>fixed</u> heads. As the difference is being formed, the gain can be increased to where the additional noise introduced by re-recording will be relatively insignificant. In general, then, the fixed heads are used for making cancellations, while the moving ones are used for storage and averaging.

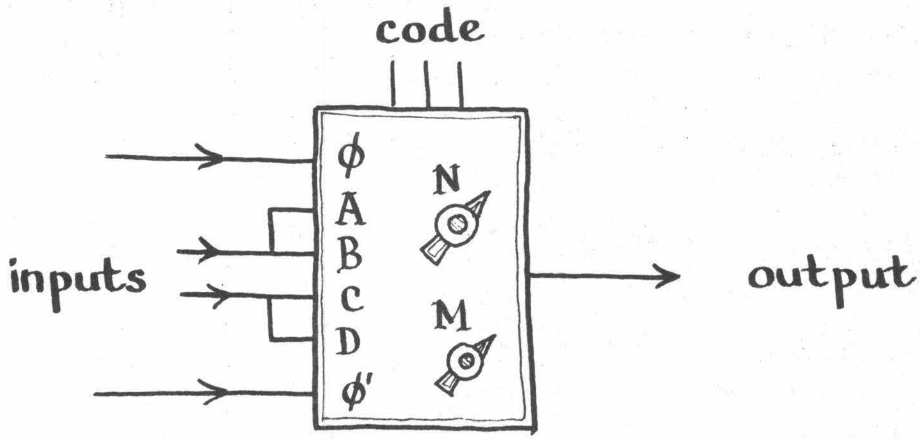
Physically the video signals are encoded as a series of period-modulated magnetic pulses recorded on the surface of a rapidly spinning metal platter. The Disc has, however, only one "modulator" circuit for converting incoming video signals into this form, and only two "demodulator" circuits for reconstituting the recorded pictures into their ordinary (analog) video form. All four heads, therefore, must share the one modulator, its output being routed internally as desired . The demodulators are shared in pairs. Heads 1 and 3 use one, while Heads 2 and 4 use the other. Because of the shared electronics, only one new picture can be recorded at one time, and at most two can be played back. In practice this is sufficient, since, aside from recording live pictures, we need only to form the sums and differences of pairs of pictures, and the pairs will appear, usually, either on Heads 1 and 2, or on Heads 3 and 4.

The Data Disc by itself is, of course, insufficient for making magnetograms. No facility even exists for transferring pictures from one head to another without going through the modulator and demodulator cards. In a sense, the real heart of the system is the separate, home-built "multiplexer" circuit (Smithson, 1972). It is this circuit, consisting basically of a wide-band differential amplifier, which performs the actual dirty work of adding and subtracting video signals. The amplifier inputs are fed by the demodulator outputs, while the output returns the processed signal to the Disc (feeding the modulator card via the VIDEO IN terminal). In response to a three-bit "multiplexer code", the circuit forms various algebraic combinations of the two input signals (see Figure 7). Code 1 gives an average, while codes 2 and 3 produce differences, in the two possible senses. In the averaging mode, the overall gain is readily adjustable by means of a potentiometer, referred to as the "N-knob". It is generally adjusted so as to give signals which do not saturate, even after repeated re-recordings. In the differencing mode, a fixed gain of about ten is used. This is intended to enhance the relatively small dynamic range of the difference signals.

In addition to the two inputs from the Disc, the multiplexer has a terminal for receiving live frames from the television camera. Code 0 directs this input to the Disc. Single recorded tracks can be played back simply by using multiplexer code 1 with only one of the demodulator cards activated, but unless the N-knob is advanced, they will seem

Figure 7: The multiplexer code

The multiplexer circuit has six video inputs, of which inputs (A and B) and (C and D) are normally operated in parallel. A three-bit binary code directs various combinations of these inputs to the Data Disc. Code 0 is used to direct live pictures onto the Disc, while codes 1, 2, and 3 are used to form averages and differences of the recorded pictures. The averaging gain is adjustable by means of an easily accessible potentiometer known as the "N-knob".



Multiplexer Code	Binary Form	Function	Comment
0	000	ϕ	live picture
1	001	$N(A+D)$	average
2	010	$10(B-C)$	difference
3	011	$10(C-B)$	inverted difference
4	100	$-M(A+D)$	inverted average
5	101	ϕ'	live picture (opt.)

Figure 7.

to have rather low contrast, since they are being averaged with nothing.

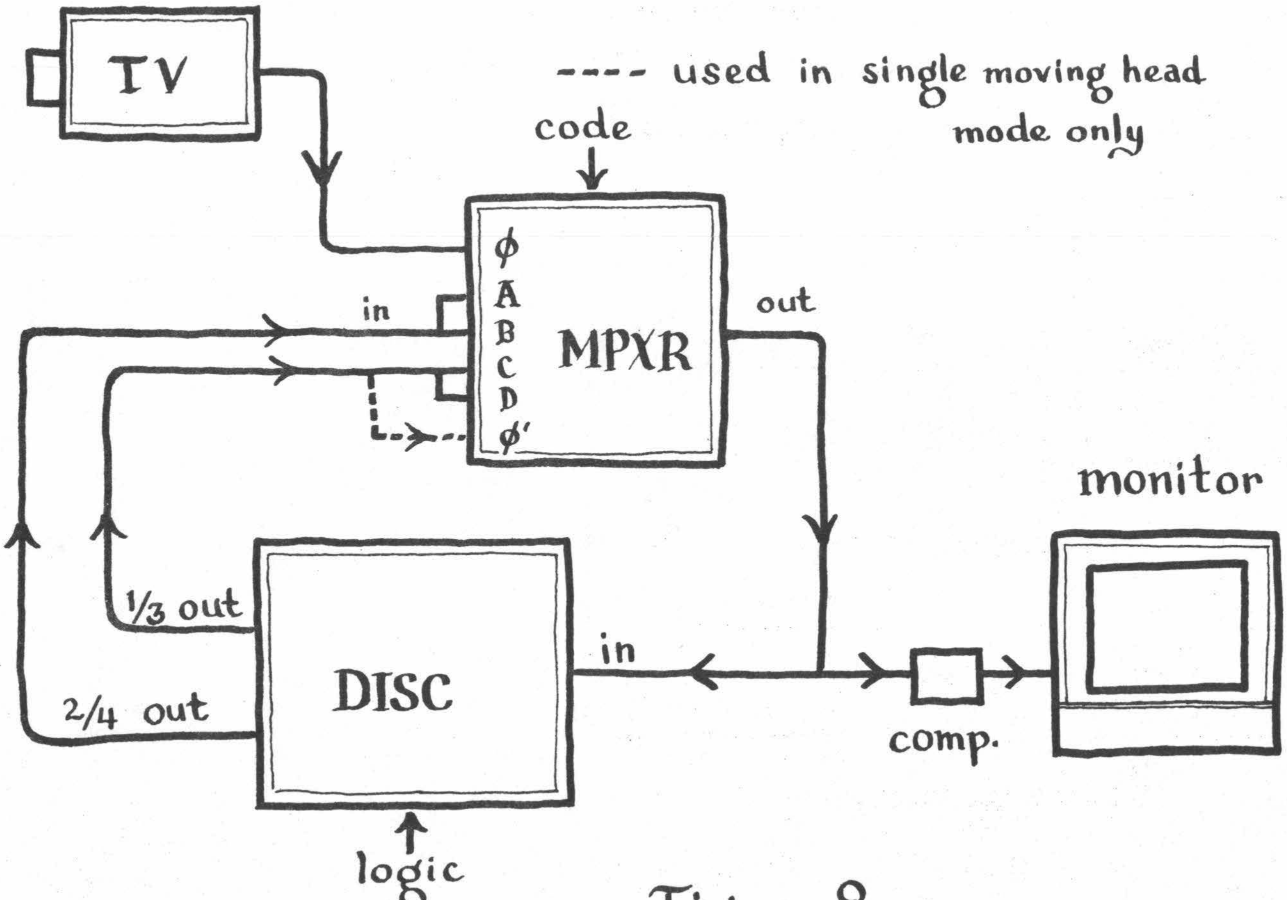
In order to be able to properly record live pictures on the Disc, it is necessary that the camera sweep be slaved to the Disc timing. For this purpose, the Disc has two "clock" heads to supplement its four video heads. One clock track provides a marker indicating where, physically, the picture should begin, while the other indicates where the individual lines should begin. The coordination between the Disc and camera timing is accomplished by means of the "sync interface" circuit (Smithson, 1972).

The camera, Disc, and multiplexer, together with their interconnecting cables, form the basic electronic unit of the magnetograph system. The recording sequence consists simply of using the multiplexer, with code 0, to direct oppositely-polarized live pictures onto the two fixed heads. Raw cancellations can then be obtained by playing back the recorded pictures in pairs, with multiplexer code 2 or 3, and re-recording the difference. Finally, code 1 can be used to average together the raw cancellations into a final composite. (The reader who is interested in a more detailed description of either the recording or averaging routine is referred to Appendix IV).

Figure 8: The electronic system

The magnetograph electronics consists, basically, of the television, multiplexer, Disc, and monitor, connected together in a simple loop, as shown. A picture cannot be recorded on the Disc without at the same time appearing on the monitor. Thus all the processing steps are apparent to the operator. The compensator circuit ("comp.") is intended to remove a slight distortion and shading introduced during the recording process.

When only one moving head is working, the Disc output serving that head can be connected to an auxilliary multiplexer input, so that recorded pictures can be played back directly, without averaging (by using code 5).



---- used in single moving head mode only
TV
code
MPXR
ϕ
A
B
C
D
ϕ'
in
out
monitor
1/3 out
2/4 out
DISC
in
comp.
logic

Figure 8.

K. The Computer

Although the basic technique for making magnetograms is quite simple, there are obviously a great many individual steps involved, and, in order to obtain acceptable results, those steps must be executed in rapid succession. In the original magnetograph, the task of coordinating all these efforts was accomplished by means of a home-built patch-cord controller (Smithson, 1972). The controller worked quite well, but after a year or so of operation was supplanted by a standard commercial minicomputer (DEC PDP-11). The computer is considerably more flexible, but also, it seems, less reliable (see troubleshooting section, Appendix VI).

Access to the computer is via a mechanical teletype keyboard, the program being loaded on punched paper tape. The The computer, in turn, interacts with the outside world through an interface panel. (The interface unit is actually just a collection of simple, two-stage, transistor amplifiers which act as a buffer between the computer and the external devices). There are 48 separate output lines which can be activated. About half of them are used at present.

In order to control the sequencing of the operations, the computer must also be capable of responding to certain external inputs, the most important of which is the clock track signal. By keying the reading and writing of frames to the receipt of clock pulses, the recorded pictures may be maintained in precise electronic registration throughout the processing routine. For convenience, even tasks which need not be strictly synchronized to the clock, such as the stepping of the moving heads, the home commands, and the switching of the KDP, are performed by the same "interrupt" routine. Hence they too occur at precisely the moment a clock pulse is received.

Because of the way the program is constructed, the sizes of the units that can be averaged together into a magnetogram come naturally in powers of two. The various averaging options are specified by a number N (no connection with the N-knob on the multiplexer), the meaning of which is that 2^N live pictures go into making the final composite. The most commonly used modes are $N = 6$ and $N = 7$, corresponding to 64- and 128-frame averages respectively. The highest possible mode, $N = 9$, involves 512 live frames. The resulting 256 raw cancellations require the full storage capacity of the Disc (using 128 tracks on each moving head). To make still larger averages, one could combine a series of $N = 9$ cancellations, but it is not clear that any significant improvement in sensitivity could be achieved in this manner. One is already at, if not past, the point of diminishing returns, where the extra noise added by re-recording is comparable with that gained by averaging.

Details of the computer program, and in particular, the method by which the recording of frames is synchronized to the clock track are given in Appendix V.

L. Operating the Magnetograph

In order to gain a better feeling for the interaction between the various parts of the magnetograph, a description of the system in action may prove useful. It is essential to understand that the video monitor is connected directly to the multiplexer output (in parallel with the Data Disc). A picture cannot be written on the Disc without, at the same time, appearing on the monitor.

Daily operation begins with an "initial dialogue", in which the operator specifies to the computer the number of frames to be averaged, the polarity convention to be observed, and so on. Since it is described fully in the operator's manuals at Big Bear, it need not be discussed here. Having set up the operating parameters, the real action starts with the receipt of a "spar ready" pulse. This pulse, generated by a relay on the telescope, indicates that it is okay to flip the mirror into the beam. As the mirror flips in, a live picture suddenly appears on the screen (by default, the multiplexer shows the live picture (code 0) unless instructed otherwise). At first it is very bright, but within a fraction of a second the camera's automatic gain control takes hold, and the picture settles down to a normal level.

As the processing starts, lights begin flashing on the interface panel. Each time one of the 48 output functions is activated one of them blinks. In addition, two three-digit neon display tubes indicate the numbers of the tracks on which the moving heads are placed. The numbers increase as the heads step in, first one, then the other. As they move, the picture on the monitor changes. One sees the live picture in one polarity (for 1/15 second), then in the other polarity (for 1/30 second), then the cancellation (again, for 1/30 second).

The rhythm of alternating live and cancelled pictures continues until the whole sequence has been recorded. Soon the Nixie tubes indicate the maximum track number that will be used in making the cancellation (usually 16 or 32). Instantly the number is reset to zero, and the program pauses, giving the moving heads time to home. As the mirror flips out the live picture disappears. Now the processing begins. The heads move, and the numbers rise, but faster this time. On the screen one sees the cancellations, in bursts, as they are read back and combined. Between the cancellations the screen is blank. Again the heads reach the innermost track, and the program pauses as they home. The screen becomes blank for longer and longer intervals, as the heads spend more and more of their time searching for intermediate averages. The cancellations appear in short, isolated bursts. At last the final composite appears on the screen and remains, frozen. In the "manual" camera mode a bell rings, and the operator is asked to make a decision as to whether or not the picture should be included in the day's time-lapse, movie. In the "automatic" mode, it is simply photographed, and then, after a second or so, disappears. Once the picture has been taken, the interface unit goes dark, and the computer sits idling, waiting for the next "spar ready" pulse. When it arrives, the cycle will be repeated.

Throughout this process, a second monitor (close to the telescope) is plugged directly into the video output from the camera. On it one sees only the live images, and nothing of the processing going on below. During the recording sequence, while the KDP is being modulated, the magnetic brightness features show a clear 15 Hz blinking.

M. Possible Improvements in the Videomagnetograph System

The quality of magnetic cancellations is generally judged in terms of two key factors: resolution and sensitivity. With the videomagentograph, as with most other systems, interesting features seem to lie at the limit of detectability, and one always hopes that the performance were just a little better.

Certainly the present magnetograph is not perfect. One can easily imagine many practical improvements concerning, say, operating convenience, or flexibility of processing; but it is less clear to what extent one might hope, even with better equipment, to fundamentally improve on the quality of the results. The problem, basically, is that the magnetograph already operates close to the point at which its performance is limited more or less equally by the light level, the camera, and the recording device. While a deriortation in any one will degrade the results, an improvement in the same, by itself, will not necessarily help.

The spatial resolution, for example, is limited primarily by the cumulative effects of seeing and image motion during the 5-10 second integration time. Replacing the present 500-line camera with a more expensive one giving 1000 lines would not improve the resolution. Assuming the light-sensitive surface to be made of the same material, the number of photoelectrons liberated during the integration cycle would be the same. Indeed, the smaller resolution elements would require a correspondingly longer integration time to achieve the same signal-to-noise. Exactly the same effect could be achieved by doubling the image size on the present tube. Thus while the more expensive system might be expected to show a larger portion of the sun at the present recolution, it could not show individual features any more clearly.

As has been indicated before, the reason that the integration time has to be so long is that the recorded video signals are noisy ($\sim$1%), and a large number must be averaged to obtain the kind of sensitivity required for magnetic work ($\sim$.1%). If the light level is low, the noise is statistical, originating in the camera. If it is high, the noise is electronic, being inserted during the recording process. One can take advantage of improvements in the quality of the live video signals if and only if the quality of the recordings can be improved as well.

The problem of improving the live signal by increasing the light level can be approached in either of two ways: by physically increasing the number of photons received, or by making more efficient use of those already gathered. The quantity of photons can most easily be increased by using larger apertures and faster beams. An f/1 beam, for example, would increase the present light level by a factor of nearly 1000 (and also burn up everything in its path). More realistically, an f/15 beam (which is about the limit that can be used with even the best narrow-band filters) could increase the light level by a factor of four. A faster beam would, however, imply a smaller final image, and the use of a higher resolution camera (otherwise the finer features would become lost among the scan lines). Alternatively, the present image scale could be retained if a larger aperture were available (and this is the more practical solution, since a 1000 line system is extremely expensive, requiring special monitors and a special Disc).

The light level can also be improved by using filters with higher transmission. In this regard, one might hope, mainly, to reduce the losses due to scattering and absorption in the polaroids. For a filter with six elements, an improvement in the individual transmissions from, say, 80% to 90% would raise the overall efficiency be a factor of 2. In principle, the present transmissions of ~5% could be increased by an order of magnitude. Similarly there is no reason to suppose that the sensitivity of the detector could not be increased by a factor of 4 or 5.

If all these refinements were in fact made, it is not inconceivable that all the light necessary to extract a statistically significant difference signal could be gathered within a fraction of a second -- perhaps even within the space of two video frames. Indeed, as the integration time is reduced, the requirements regarding sensitivity become less stringent, since the individual magnetic and velocity elements are more nearly resolved. Because the resolution is limited by seeing, however, it is not obvious how much improvement can be expected for a given reduction in integration time. One has the feeling that the seeing does most of its damage within the first couple of seconds. The difference in resolution between a 5- and a 10-second exposure, for example, is not very great.

Quite aside from any effort to improve the resolution by decreasing the integration time, one can work on improving the sensitivity of the system to weak fields. While the improved signal-to-noise that would result from better light levels, better cameras, and better recordings is, of course, helpful, other approaches can be used. In particular, one can try to increase the signal itself, so that less sensitivity is required to detect it. The line $\lambda5324$ by no means gives the largest percentage modulation that can be obtained for a given field strength.

As has been explained before, the magnitude of the signal is determined both by the sensitivity of the line to magnetic splittings (as indicated by its g-factor) and by the steepness of the line profile. The slope of the wings is, of course, degraded by the finite bandpass of the filter, particularly for weak lines. Thus, provided one can tolerate the loss in light, a narrower bandpass will tend to improve the signal. More importantly, it will permit the use of other lines, whose sharp, but possibly shallow, profiles are inherently more sensitive to weak Zeeman splittings and Doppler shifts: $\lambda5250$, for example, or $\lambda6103$. Other portions of the spectrum may also be useful. Indeed, for magnetic work, the most favorable lines are found in the infra-red, where, because of the λ^2-dependence of the Zeeman effect, the splittings can actually exceed the line width. Unfortunately, the Plumbicon is not a very good camera for use in this range (its sensitivity falling off sharply beyond about 6000 Å), and good filters are hard to come by.

N. Alternatives

While, as we have just seen, it seems probable that future improvements, particularly in the area of filters, cameras and recorders, will materially enhance the performance of systems such as the videomagnetograph, it is always possible that other arrangements of the same basic components could produce even better results. Of the many variants which can be imagined, only a few have been tried. Indeed, the success of the magnetograph in its present form has discouraged the investment of time and money which would be required to accurately assess the merit of most of the alternative techniques. At the same time, it is not clear that all of the present complexity is either necessary or desirable.

Most of the schemes to be proposed will sacrifice the one feature for which the videomagnetograph was specifically designed: namely the availability, in real time, of the final, completed cancellation. In retrospect this does not seem like such a big sacrifice, for in practice, the ease with which the system performs the cancellations has proved a far greater asset than the speed with which they are produced. In fact, the system is generally run on a routine survey-type basis, with many of the results not even being examined until months, or even years later.

Thus the main practical advantage of the real time cancellations is that they alert the operator to mechanical and electronic failures as they occur. But even this is not essential, for the experienced observer can usually tell whether or not the filter and KDP are working properly simply by examining the live, modulated image (although the enhancement in contrast made possible by the television camera is certainly helpful in bringing out the magnetic "blinking").

1. Photographic Averaging: In its present form, the system requires that each raw cancellation be subjected to a barrage of averaging before acceptable signal-to-noise can be achieved. A considerable simplification in the system, and a possible improvement in the results, could be achieved if one were willing to do the averaging directly on film, using the camera with which the time-lapse movies are made. This would involve nothing more than holding the camera shutter open as the individual cancellations are displayed, one by one, on the monitor. The effects of the separate frames (each too lightly exposed to make much of an impression on its own) would add to make a final composite just as accurate as if they had been summed on the Disc. Indeed, the result would in some ways be superior,

since most of the transfer noise would be avoided.

This combination of using the Disc to extract the differences, and the film to form their averages, has the advantage that it does not require the use of the moving heads (which have traditionally been a great source of trouble), nor the services of the computer, which is used mostly to direct their progress through the averaging routine. Indeed, the recording loop is so simple that a small hard-wired controller, driven by the clock track pulses, would be entirely sufficient to coordinate the operation; and such simplification would almost certainly improve the reliability of the system as a whole.

On the Disc, only two heads are required. A live picture in one polarity is recorded on the first, the KDP is switched, a live picture in the opposite polarity is recorded on the second, and finally, the two are played back together, with the difference, as formed by the multiplexer, being displayed on the monitor. Since the composite is being formed simultaneously with the acquisition of the data, the processing time, which usually accounts for more than half of the time between frames, would be eliminated, and hence much more rapid sequences of magnetograms could be taken. In addition, the number of live frames used in making the average could be varied simply by changing the exposure time.

One of the main drawbacks of the direct-averaging scheme is that the cancellation appears on the screen for only 1/30 second out of each 4/30 second recording sequence. During the rest of the time, the screen must be left blank to avoid fogging the film with undesired information. The display would not, therefore, be very attractive, visually. On the other hand, an hourly test exposure on Polaroid film could verify whether or not the system was working. For the movies, incidentally, any reasonably fast film could be used. A cancellation involving 30 live frames, for example, would have a total exposure time of 1/2 second. With normal monitor brightness, this calls for something like f/4 at ASA 100.

Since this technique only requires the recording of two live frames at a time, it might be profitable to consider the use of devices other than the Data Disc for storing them. The newly-developed solid state recorders, for example, using charge-coupled storage devices, are particularly attractive. If their quality of recording were acceptable, an extremely compact and efficient magnetograph could be constructed.

2. <u>Delay-line schemes</u>: One could do away with the recording medium entirely if it were possible to devise a scheme for subtracting the live images directly. Since at least part of the present averaging is required simply to recover the signal lost in recording, this would, again, not only simplify the system, but also, hopefully, improve the quality of the results.

One method for obtaining direct cancellations involves the use of a non-storing delay-line-type circuit to divert each live picture for 1/15 second. As it emerges from the delay (assuming that the KDP is being modulated at 15 Hz), the signal will have an opposite polarity to that of the current live picture. Thus by combining the two signals via the multiplexer (using code 3 or 4), one could obtain a continuous, if somewhat noisy, "live cancellation".

As with the first scheme, a simple hard-wired controller, modulating the multiplexer and KDP in synchronism with the clock track would be sufficient to keep things ticking; and averaging could be accomplished simply by taking a long exposure of the "live" cancellations flashing on the monitor. (The screen would again have to be left blank on alternate 30th seconds to avoid showing the "mixed polarity" frames which arise immediately after each switching of the KDP).

The principal problem with delay-line schemes is that, even if such a circuit could be constructed at a reasonable cost, the emergent picture would probably be too distorted to cancel properly. Nonetheless, the performance would presumably be much more reliable, or, at least, consistent than that achieved at present, since neither the Disc nor the computer would be used.

3. The two-camera mode: A more practical way of cancelling the live pictures without use of Disc or computer, is to use two separate television cameras. By means of beamsplitters, one can be fed, say, by an image in right-hand circular light, while the other is fed by an identical image in left-handed light. (Alternatively, one could be in the red wing, and the other in the blue wing of a particular line). Once the images have been obtained, there is nothing to prevent one from running them directly into the multiplexer, forming, thereby, a continuous live cancellation. As before, the background noise can be brought down to an acceptable level simply by taking a sufficiently long exposure of the monitor, integrating the images on film.

The problem with the two-camera scheme is that it is very difficult to find cameras whose characteristics are closely-enough matched to give good results. The Plumbicons, for example, which are typical of reasonably high quality cameras, tend to vary in sensitivity from point to point over their target areas by as much as 10-20%. Worse still, they have geometric non-linearities on the order of a few percent, which make precise registration between the images nearly impossible.

Even if the cameras are matched, one has to take special precautions to assure that a fixed relationship is maintained between their gains. Otherwise, the zero level will drift, causing the "cancellation" to become dominated by one or the other of the live pictures.

Overall, then, the sensitivity of the two-camera mode is only marginally adequate for magnetic work, and, at least with present filters, the signals arising from most normally-encountered field strengths would be too weak to distinguish from the general background splotchiness.

4. Cancellations on the monitor: A rather different scheme, which is also capable of producing cancellations without using either the Disc or the computer, involves using the video monitor to display, successively, live pictures having the character of photographic positives and negatives. By modulating the live picture in synchronism with the KDP, one can arrange things so that a normal live picture showing, say, the magnetic features in right-handed light, will appear on the screen, followed by a negative in left-handed light. On a long exposure, the two images will add together in exactly the way a photographic positive and negative are added in the classic Leighton technique. (Once again, the mixed-polarity pictures have to be rejected by using a dark screen on alternate frames). With a Philips Plumbicon, the production of the positives and negatives is particularly easy since the camera controller contains an internal circuit expressly intended for generating inverted ("negative") video signals which will photograph as direct positives.

Although results can be obtained in this way, the scheme suffers from a number of obvious limitations. The most important of these is the fact that the monitor has to be operated in the relatively narrow "linear" range of its response. This means that only a limited dynamic scale can be displayed. As a result, the cancellations will have very low contrast. In addition, even in this favorable range, the camera controller has to be very carefully adjusted if one is to get truly complementary performance in the positive and negative modes. Finally, problems associated with reciprocity failure in the film are encountered -- the final result depends not only on the intensity, but also on the order of the individual exposures. Because of these problems, the success or failure of a given series of settings cannot be accurately judged until after the film has been developed, and even then one is lucky to be able to see differences of less than 20-30%.

5. Film/Video Hybrid System: While neither the two-camera mode nor the positive/negative superposition technique seems to offer a very attractive alternative to the present magnetograph, a good case can be made for the development of a sort of hybrid system combining the proven efficiency of film, for recording live signals, with the simplicity and accuracy of cancellation that can be achieved using video techniques.

In this scheme, a slightly-modified motion picture camera, operating in tandem with the filter and KDP, would be used to photograph the live image. By gating the KDP to the film advance, quick pairs, with alternating polarity, could be taken (note that, since the film "integrates" only for as long as the shutter is open, and since the KDP switches essentially instantaneously, there would no longer be any problem with "mixed polarity" frames). The film could be developed to quite high contrast, so as to bring out the magnetic (or velocity) signal; and the success of the run could easily be assessed simply by examining it. Not only could shorter exposure times be used, but also the choice of filter would no longer have to be restricted by the sensitivity curve of a particular television camera -- any image bright enough to photograph could be used.

With the live image being permanently recorded on film, the subtraction system could, if desired, be placed at a location remote from the telescope, where routine maintainence and repairs could be more easily performed. In addition, no data would be lost during such "down time".

In order to subtract images recorded on film, one would have to construct a special transport to which the television camera could be attached. Since time and seeing fluctuations are no longer an issue there would be no compelling reason to shuffle rapidly between pictures of opposite polarity. In fact, each recorded pair should contain sufficient information for constructing a complete magnetogram. The idea, then, would be like that used in the old magnetograph, where one records a long series of pictures of the first frame on one moving head, then advances the film and records a comparable series of pictures of the second frame on the other head. Once recorded, the video frames could be played back in pairs and subtracted. While the individual cancellations might be quite noisy, they would, when averaged together, give an acceptable result. The average, incidentally, could be formed either electronically or photographically. Still better results might be obtained by superimposing the results of several different tries, although if more than one of the original pairs were employed problems having to do with image motion might arise.

One of the greatest advantages of the hybrid system is that the live, uncancelled images are permanently preserved. Not only does this mean that important data can be reprocessed in the future, (and by better techniques should they become available), but it also means that one can determine exactly where, on the sun, each bit of magnetic (or velocity) signal originates. With the present system, where only the cancelled result is preserved, the origin of the signal can only be guessed at by comparison with other pictures, taken at approximately the same time, but through different filters, and with different cameras. Particularly in the study of Doppler cancellations, where the usual solar landmarks, like sunspots and faculae, tend to disappear, the availability of the uncancelled pictures is almost essential.

III. DESCRIPTION OF DATA

A. Operation at Big Bear

After the first year of operation and refinement at Caltech (Smithson, 1972), the magnetograph was moved to its permament home at Big Bear Solar Observatory (Zirin, 1970) in late 1971. The first useable data were obtained in October.

At the time of installation, and throughout the period to be described in this thesis, the solar telescope there consisted of a single "spar" with three principal 10" objectives. One of these, a doublet, fed a Coudé spectrograph; while the two remaining singlet lenses fed time-lapse cameras mounted in the standard filter-photoheliographic configuration on optical benches protruding out the back of the spar. Because of their positioning, these two systems were referred to as the "East" and "West" cameras, and most of the time they were used for making high-resolution observations in on- and off-band H_α. In addition to the three main lenses, a smaller telescope (the 8.6" "Singer-Link") rode piggy-back on top of the main spar, and because of separate guiding was able to take continuous full-disk movies (also in H_α).

The magnetograph, too, was mounted on its own optical bench, but this time one bolted to the outside of the tube, and sharing its 10" lens with the West Camera. A pair of diagonal mirrors directed the beam first out through a hole

Figure 9: The observing site

The main telescope at Big Bear consists of an equatorially mounted spar. An electromechanical "flip mirror" placed on the optic axis directs light out through a hole in the declination axis, whence a second 45° mirror directs the light along the axis of the auxillary optical bench to which the magnetograph components are attached. An achromatic enlarging lens placed within the declination gear relays the prime focus image (formed close to the flip mirror) onto the television camera. Wires and cables connect the optical components with the electronic system in the magnetograph room below.

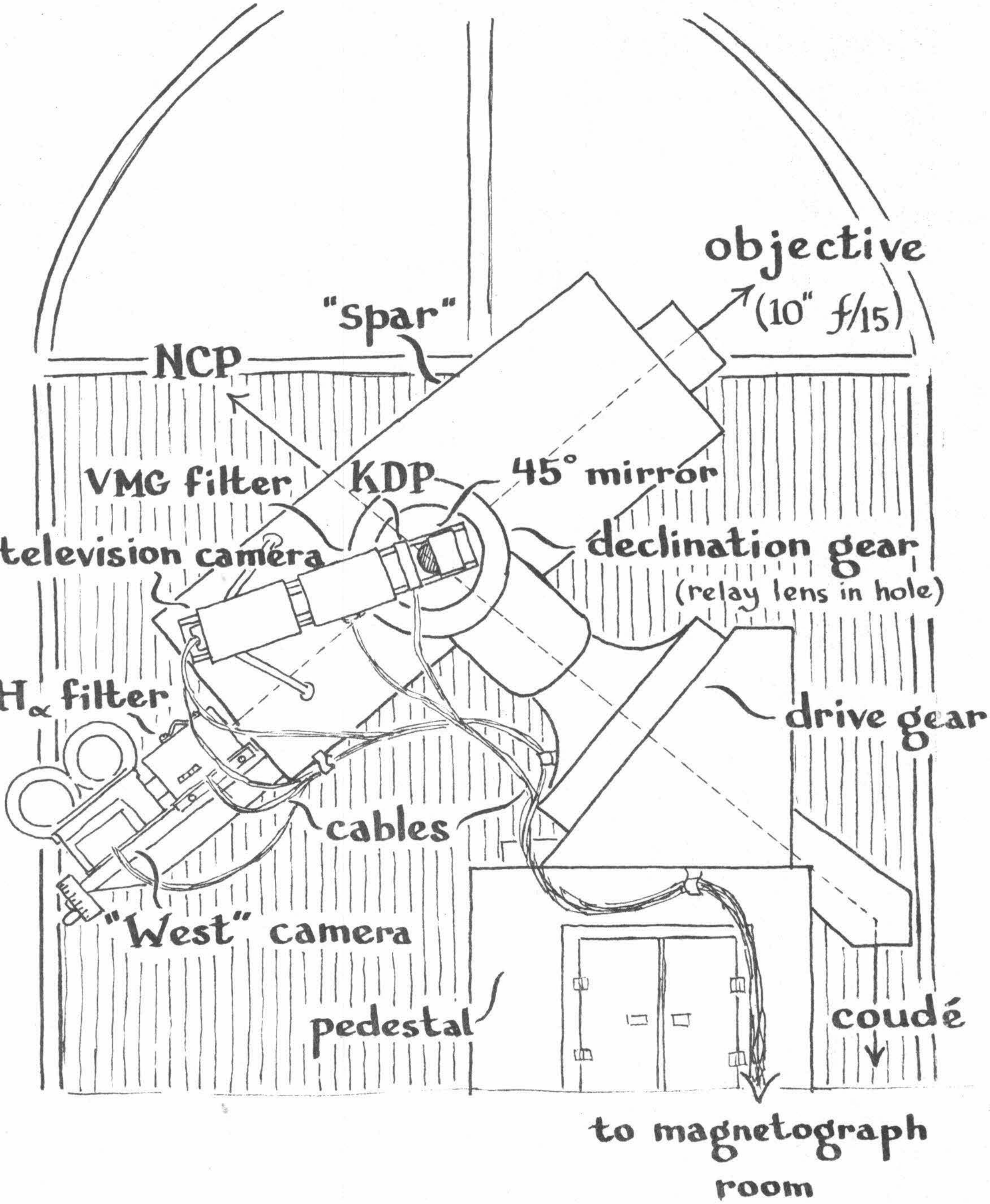

objective
(10" f/15)
"Spar"
NCP
VMG filter
KDP
45° mirror
television camera
declination gear
(relay lens in hole)
H_α filter
drive gear
cables
"West" camera
pedestal
coudé
to magnetograph
room

Figure 9.

Figure 10: The optical system

The optical system of the videomagnetograph is a standard photoheliograph configuration, folded by means of diagonal mirrors so as to accomodate the restrictions imposed by the necessity of mounting the optical bench on the outside of the spar. The final image size (and hence the field of view) can be varied by moving the camera and refocusing. Normally it is about 5" in diameter. The unused portion of the image is rejected within the spar by means of a field stop.

The system has been found to work best with the filter and KDP located as close as possible to the camera.

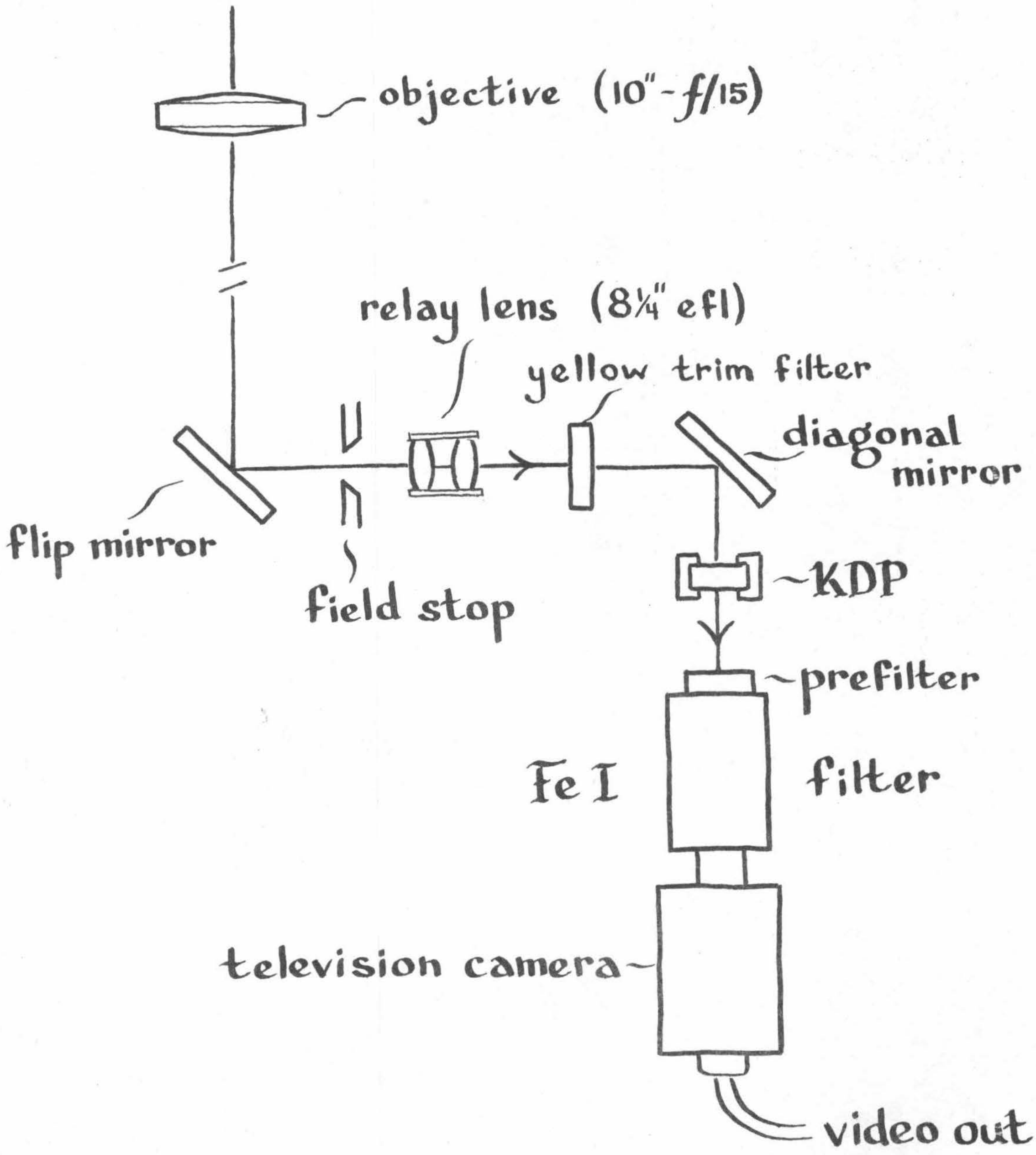

objective (10"-f/15)
relay lens (8¼" efl)
yellow trim filter
diagonal mirror
flip mirror
field stop
KDP
prefilter
Fe I
filter
television camera
video out

Figure 10.

in the middle of the declination gear, and then along the axis of the bench (see Figure 9). Since a permanent mirror would block the light to the West Camera, a beam splitter was tried but the idea had to be rejected because of the astigmatism it introduced into the transmitted beam. The rejection of the beam-splitter is probably just as well, for polarization introduced by reflections, particularly near the cut-off wavelength, can seriously affect the performance of a magnetograph. The alternative was an ordinary aluminized mirror mounted on a specially-constructed solenoid-operated flipping machine. When the magnetograph was to be used, the mirror could be flipped into the beam, while when the photoheliograph was to be used, the mirror could be flipped out. The problem with such arrangements is that even a very small, random misalignment of the mirror can cause large displacements in the image plane (which, in this case, is about 8' away), and in spite of many precautions, a number of our movies show substantial jitter.

To return to the description of the magnetograph optics (Figure 10), the prime focus image, which is formed inside the tube, is relayed back to the TV camera by means of an enlarging lens (8½" F.L.) inserted into the hole in the declination gear. At the prime focus, the solar image is about 1½" in diameter. A tilted metal plate, painted white to reflect the heat, occults all of the image except for a selected circle, about ¼″ in diameter. This portion , which is enlarged about three times during the projection, is just sufficient to cover the camera faceplate. Because of the location of the prime focus, the field stop and relay lens feeding the magnetograph are entirely separate from those feeding the West Camera. In principle, then, the two systems could be pointed independently. In practice, however, the adjustment was so difficult (requiring one to actually climb inside the spar to move the field stop and re-center the relay lens) that every effort was made to keep the telescopes aligned. Thus all three cameras (East, West, and magnetograph) were pointed at the same region on the sun, and, in fact, showed similar-sized areas (about $4'\times 6'$ for the magnetograph; a slightly smaller field for the filtergrams). At times, variations in the available light level (caused, for example, by changes in filters, or simply by seasonal variations) required or permitted changes in the image scale. This could be easily accomplished by changing the position of the TV camera on the bench. Moving it up and refocusing, resulted in a smaller image, while moving it back gave a larger one.

Since the West Camera was normally making an exposure every 10 or 15 seconds, a considerable degree of coordination was required to avoid having the magnetograph mirror still in the beam at the time of exposure. A relay attached to the main timer, sent an electronically-delayed pulse (the "spar ready" signal) to the computer. The 1/4-second delay was sufficient to give the camera time to complete its exposure cycle. The operator did, however, have to be constantly careful to use integration times short enough to fit between the camera pulses. With a 7-second camera timing, a $N = 6$ (64-frame) average could just be squeezed in, while with 15 seconds, or more, $N = 7$ (128-frame) averages were possible.

Since conditions in the observing dome at Big Bear were hardly ideal for the storage of delicate equipment, the electronic portion of the magnetograph system was located in a separate room on the floor below the main dome. Figure 11 gives an impression of the setup there. The only connections between the magnetograph room and the spar were a long ($\sim$75′) electronic cable connecting the TV camera head to its control unit, a pair of high-voltage coaxial cables for driving the KDP, a power wire to energize the flip-mirror solenoid, and the wire carrying the timing signal from the West Camera. Because of the rather extreme fluctuations experienced in the dome, particularly during the winter, the filters had to be wrapped in electric heating pads to prevent uncontrollable temperature changes.

Naturally, operation of the system required a considerable amount of running between the magnetograph room and the spar. Adjustments in, for instance, focus and KDP angle had

Figure 11: The magnetograph room

The bulk of the magnetograph electronics is located in a room (formerly occupied by the spectrograph) below the main observing floor. The functions of the various components are described elsewhere in the text of the thesis. "Rotators A and B" are used in firing the movie camera.

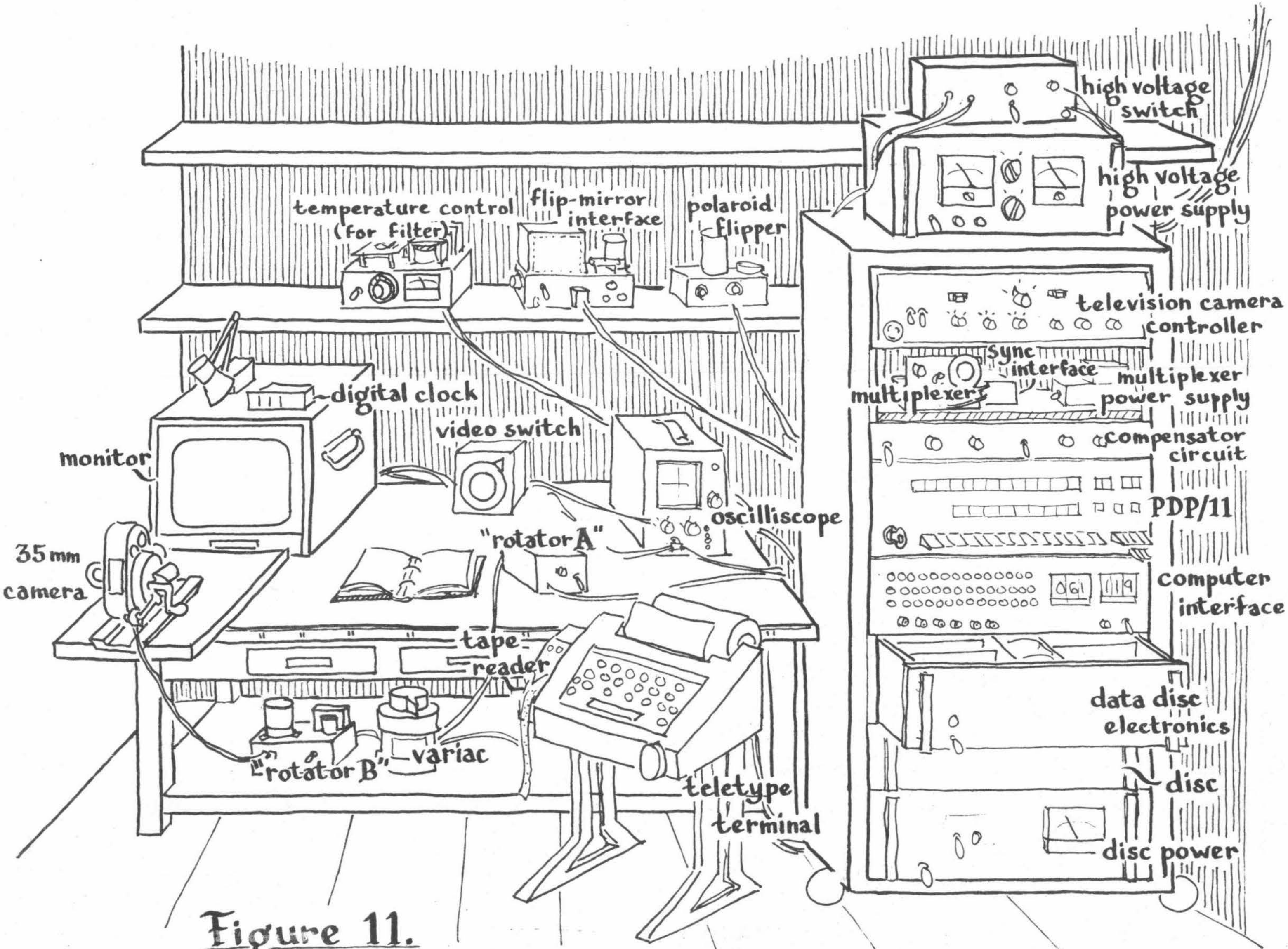

high voltage switch
high voltage power supply
temperature control (for filter)
flip-mirror interface
polaroid flipper
television camera controller
sync interface
multiplexer
multiplexer power supply
compensator circuit
PDP/11
digital clock
video switch
monitor
oscilliscope
"rotator A"
35mm camera
computer interface
061
119
tape reader
data disc electronics
disc
"rotator B"
variac
teletype terminal
disc power

Figure 11.

to be made directly at the telescope. The operation was considerably simplified by installation, in the dome, of a remote video terminal, on which either the live or processed image could be displayed.

B. Chronology of Changes in the Magnetograph System

When first installed, in September, 1971, the magnetograph used a 1/8 Å double bandpass filter tuned to the Fe I line, λ5324 (Appendix I-A); and was operable in either the magnetic or the Doppler mode. The filter had been developed for use in a filter-photographic magnetograph (Ramsey, 1969), and worked quite well. Electronically the configuration of the system remained essentially as described in Smithson's thesis (1971), with the sequencing of operations being directed by a patch-cord programmable controller.

No major optical or electronic changes occurred until February, 1972, when the original controller was replaced by the present PDP-11 minicomputer. In August, it became necessary to return the λ5324 filter (to Lockheed Solar Observatory, from whom it had been borrowed), and a major change was therefore required. By chance, it was found that the 1/4 Å Zeiss H_α filter (previously used on the East Camera), could easily be converted for magnetic work at 6103 Å (see Appendix I-B). At first the signal was extremely strong (even better than that achieved with the original 5324 filter, but after a few days it began to degrade. This was due, apparently, to errors in the pre-filter causing a loss of light, but the problem was not immediately recognized, and most of the data for August is noisy. Since the Zeiss was used in a simple single bandpass mode, Doppler cancellations were impossible. It has since been discovered that the Zeiss can also be operated in a double bandpass mode (Michalitsanos and Bhatnagar, 1975). Not only does this make Doppler work possible, it also significantly improves both the light level and the magnetic signal strength.

During this time a new filter was being constructed for permanent use on the magnetograph. On September 8 it was installed. Since the Spectra-Optics filter (Appendix I-B) had been designed over a year earlier, the line chosen was λ5324. Our experience with the Zeiss suggests strongly that even better results could be obtained at 6103. Nonetheless, the Spectra-Optics filter delivers a very respectable signal, and has several times the transmission of the original Lockheed filter.

Of the many electronic problems which have afflicted the magnetograph system, one of the worst was the loss of a moving head in July, 1972. The problem was caused by a crack developing in the ferrite chip, and, due to the difficulty of repairing heads, necessitated changing the program so as to avoid using it. As is explained elsewhere, the processing can be done just as well with only one moving head, but at the expense of spending more than twice the normal time doing it.

Serious problems were also encountered with the KDP. Even though the crystals are rated for use with DC voltages, it seems that prolonged exposure to a signal of the same electrical polarity will cause an irreversible change in the transparent electrodes. After a few hours of use, a brown splotchy pattern (presumably due to some kind of electrolysis) begins to develop. In a few weeks, the crystal is too badly fogged for use of any kind. Once the cause of the problem was discovered, the program could simply be modified so as to drive the crystal in a well-balanced fashion, applying both polarities for equal amounts of time. Since the modification was made, relatively little trouble has been encountered with the KDP's; and even during the preceding period almost no observational time was actually lost, since two crystals were on hand, and one could be used while the other was being repaired.

C. Data: The Movies

While data can be stored permanently on the Disc, its capacity is very low in comparison to the potential output of the magnetograph system. In the period between November, 1971 and December, 1972, for example, (during which observations were made on ~190 days) more than 100,000 different cancellations were produced. The only practical medium for the storage of such vast quantities of material is film. Hence, each cancellation, as it was being displayed, was photographed on a hand-wound 35 mm movie camera (see Figure 12). The camera was equipped with a solenoid-activated escapement, and the solenoid, in turn, was activated by the computer. Plus-X film was used throughout, developed to about ASA 300 in D-19. The image of the monitor is ~15 mm wide. If it were any smaller, the individual scan lines could not be resolved. While some of the daily sequences consist of merely a frame or two, others extend over more than 100 feet. Printed onto 16 mm film, the data accumulated within the course of a typical 8-hour run can be projected in less than a minute.

As indicated in Figure 12, the individual frames are identified by means of a clock and date card placed on top of the monitor. If properly illuminated, these form a narrow "data strip" above the relevant frame. Naturally the clock will indicate the time at which the photograph was taken, and not that at which the integration cycle began. A more sophis-

Figure 12: The film camera

The videomagnetograph movies are obtained by photographing the monitor on a hand-wound 35 mm. movie camera. A date card and clock placed on top of the monitor provide convenient references, while titles can be inserted simply by placing hand-lettered signs in front of the screen.

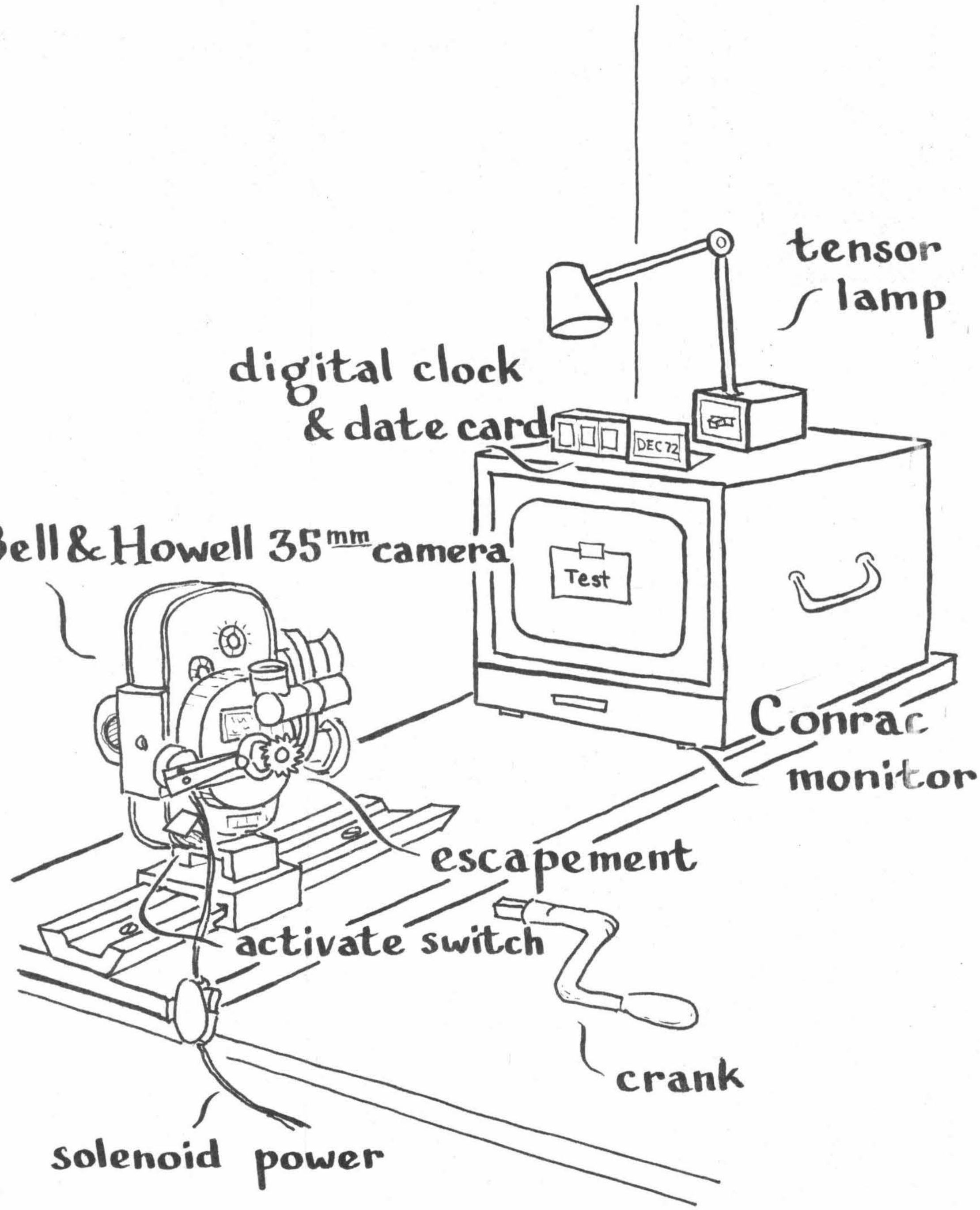

tensor lamp
digital clock & date card
DEC 72
Bell & Howell 35mm camera
Test
Conrac monitor
escapement
activate switch
crank
solenoid power

Figure 12.

ticated system would, no doubt, use an internal electronic clock, whose reading would become a permanent part of the recorded cancellation, and appear directly on the monitor. Not only would this permit one to display the correct time, but also it would simplify the photographic problem: at present the clock is simply too far from the screen and requires the use of an unnecessarily small format on the film. When individual frames are printed, the date and time have to be written on the back, if, as is usually the case, the monitor screen is blown up to fill the page.

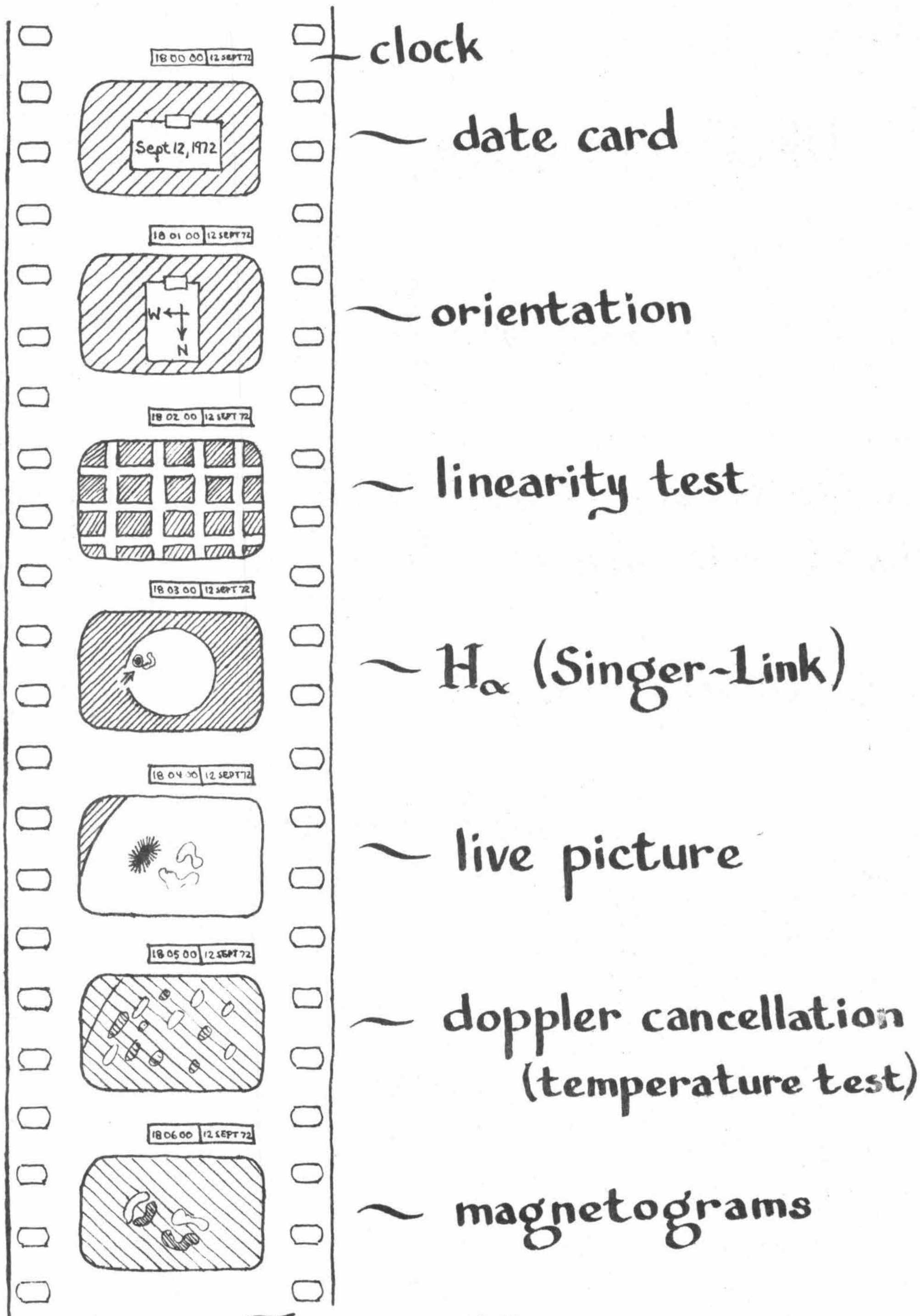
While the indicated time can usually be corrected simply by subtracting the ~10-15 second delay which normally exists between the midpoint of the integration time and the exposure, this is not always valid; for on occassion the monitor is photographed while displaying a cancellation which was originally recorded hours, or even days, before. An example would be the "Replay of Selected Frames" which appears at the end of many of the daily segments. This consists of a series of frames collected during the day (and stored, temporarily, on the spare tracks of the Disc) which are re-photographed in sequence, so that, if desired, they could be printed as a continuous loop. In such cases (hopefully labelled on the film) the reading on the clock has to be ignored. The actual times at which the cancellations were made can usually be found in the observing logs.

Because of the way in which the movies were made, titles could easily be inserted simply by holding hand-written cards in front of the monitor. Titles were used both at the beginning and at the end, and whenever an important parameter (such as the polarity convention, or the number of frames being averaged) was changed. Figure 13 shows the format of a typical magnetograph movie lead-in. In addition to the expected frames indicating the date, polarity rule, and so on, a number of other kinds of displays are included. A full-disk H_α picture, for example, was available simply by splicing in the signal from a television camera attached to the Singer-Link telescope (which was intended for use as part of an automatic flare detector). Although the quality of reproduction is not high, it is sufficient to identify the location of the region being observed. In addition, several frames indicating the appearance of the live picture are included. These will reveal any geometric distortions which may be present, and, at least in principle, permit one to determine the precise relationship between the fields and other more visible features, such as sunspots, which might be recognized on photographs taken the same day.

Not all of the frames which appear to be live pictures are actually that. Some are multiple-frame averages made by changing the word in the program which specifies the multiplexer code used in forming the initial differences, so that

Figure 13: The Movie lead-in

The normal magnetic movie is preceded by several frames of reference data. When possible, a full-disk H picture (obtained from the Singer-Link camera) is included to indicate the location of the region being observed. A live picture (to the same scale as the final cancellation) permits the location of spots to be determined, and is particularly useful in connection with Doppler work (where the spots are normally invisible).



18 00 00 | 12 SEPT 72
clock
Sept 12, 1972
date card
18 01 00 | 12 SEPT 72
W
N
orientation
18 02 00 | 12 SEPT 72
linearity test
18 03 00 | 12 SEPT 72
H_α (Singer-Link)
18 04 00 | 12 SEPT 72
live picture
18 05 00 | 12 SEPT 72
doppler cancellation
(temperature test)
18 06 00 | 12 SEPT 72
magnetograms

Figure 13.

the opposite polarity live frames are added rather than subtracted. The reason for showing the multiple frame averages is that the recorded pictures are displaced, on the monitor, relative to the live ones, due to an accumulation of small electronic delays . The multiple-frame average has the same delay as a magnetogram constructed from the same number of frames, and thus permits a more precise comparison of features than would be possible with a single uncorrected live picture. The average also gives a more accurate impression of the kind of losses in resolution to be expected as a result of varying seeing conditions. At times the composite is almost indistinguishable from the live picture, giving a hint of the penumbral fine-structure around large spots, and showing clearly the coarser modulations due to granulation. The "white-light averages" are particularly important for Doppler work, where registration often has to be determined with reference to the edges of the screen.

Alternatively, one can form a sort of "semi-cancellation" by averaging part of the live pictures and subtracting others. In this way an image is produced which resembles the live picture, but which has a ghost-like representation of the magnetic (or velocity) fields superimposed.

When necessary, averages can be distinguished from genuine live pictures by looking for the dark vertical "blanking bar" on the right hand side of the monitor screen. If things are properly adjusted, this will be present on the live picture, but not on the cancellations (and averages), since they are displaced to the right.

During the movie sequences, frames are usually recorded at a rate of between one frame per 15 seconds and one per 5 minutes, with a definite preference for the higher rates. Since magnetic features on the sun do not change very rapidly (at least at the resolution which we can obtain with the videomagnetograph), such high frame rates may seem superfluous. In a sense they are, but the idea is that a more complete record permits a more careful analysis. There are, for example, many features which are either so small or so weak that their reality can only be determined by examining an extended sequence of frames. One can also perform many simple manipulations which would not otherwise be possible. The production of photographic composites, for example, in which background noise is supressed by printing a number of good, closely-spaced frames on top of each other, has proved a useful tool for bringing out diffuse network fields (in the case of magnetograms) and supergranulation (in the case of Dopplergrams).

The problem with taking too many magnetograms is that the movies take too long to tun. Ideally one would like to see the (rather subtle) changes that occur in a day go by in a matter of a few seconds. If the movie takes a minute, one tends to forget what the picture looked like at the beginning by the time he sees the end, and thus gets the impression that "nothing happened". The interruption by occasional Doppler pictures is also rather distracting. The possibility of separating the two kinds of data by using separate cameras and separate monitors was considered, but didn't seem too practical. What is needed are edited versions of the main movies, in which the best frames of each type are assembled into short loops; but since the equipment for making such reductions was not readily available, most of the information regarding field changes has been obtained by studying prints of individual frames, supplemented by reference to the original negatives.

For Doppler movies, where real changes can easily occur in under a minute, the highest possible frame rate is always desirable. Unfortunately, the relative lack of light available for Doppler work (due to the extra polaroid which has to be added) makes very short cancellations impossible. Anything less than about N = 5 (32 frames) simply has inadequate signal, even when viewed as a movie sequence. Thus the minimum time between frames (Appendix IV) is about 5 seconds, and on most of the Doppler movies it is more like 15 or 20.

The results of the observing program are summarized in Table I.

The original 35 mm negatives, assembled into 1000′ rolls, are stored in the Big Bear collection at Caltech. There is a total of six rolls, comprising about 3500′ (700 hours real time) of magnetic coverage, and 1500′ (200 hours real time) of Doppler. There are 217 separate magnetic sequences lasting 1/2-hour or longer, showing the development of more than 50 distinct regions. The longest covers 11 hours. Of Dopplergrams, there are 93 segments covering 1/2-hour or more, the longest covering about 7 hours.

The normal magnetic polarity convention is that white corresponds to (Mount Wilson) positive, and black to (Mount Wilson) negative. Thus, for the period covered, black leads in the north, and white in the south. On Doppler cancellations, lighter-than-average features are approaching and darker-than-average features receding.

Finally, it should be noted that the mechanical clock, though it appears to read normal 24-hour universal time, is actually only calibrated over 12 hours. It will be apparent in viewing the movies, that on a few occasions when observations were made very early in the morning, it is necessary to add 12 hours to the apparent reading to obtain the correct universal time (eg. 0200 ≡ 1400 UT, etc).

Table I

The accompanying table catalogues all the movie sequences obtained during the initial period of operation. The list includes the universal time at which each sequence starts and ends, as well as the last three digits of the McMath calcium plage number for the group being observed (as identified in the NOAA Prompt Reports).

The MODE of operation is represented by the following set of symbols:

VMG:	magnetic movie, $\lambda 5324$ filter
DOP:	Doppler movie, $\lambda 5324$ filter
Z/D:	alternating, predominantly magnetic
D/Z:	alternating, predominantly Doppler
Z :	magnetic movie, Zeiss filter

The quality of the sequence is indicated in the column labelled COMMENTS. The following symbols are used:

Ex:	excellent (exceptional)
G :	good (above average)
P :	notably poor in resolution
N :	weak, noisy signal
H :	excessive contrast
Ov:	overexposed, overdeveloped, or both
Un:	underexposed, underdeveloped, or both
Gr:	bad gradient (on Doppler cancellations)
El:	electronic problems
J :	jitter between frames when projected
Wx:	bad weather
B :	bad seeing
C :	clouds
O :	no observations
S :	survey only
R :	reversed polarities

The sequences for which no evaluation is given (the majority of cases) are of average quality, with no obvious defects. When a gap of more than 1/2-hour exists in the data, the preceding and following segments are regarded as separate sequences. Gaps of less than 1/2-hour are ignored. A single time in the second column indicates that only a few frames were taken.

The last two columns indicate the duration (in hours) of each uninterrupted Doppler or magnetic sequence.

> Note: The can containing the original 35 mm negatives from most of March-May, 1972 appears to have been misplaced. The data are still available in 16 mm reproductions, however.

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
1971						
Oct. 22	1930	565	VMG	1^{st} operation @ BBSO		
23-26				O		
27	2300		VMG			
28				O		
29	1755-2315	575	VMG		3	
30	1730-1845 1845-2043 2045-0013	575 " "	VMG DOP VMG		1 $3\frac{1}{2}$	 2
31				O		
Nov. 1	2119-2351	579	VMG		$2\frac{1}{2}$	
2				O		
3	1700-1915	579	VMG		2	
4-5				O		
6	1729-2400	591	VMG	P, H	$5\frac{1}{2}$	
7	1750-2400	591	VMG	P, H	$6\frac{1}{2}$	
8-12				O, Wx		
13	1916-2340		VMG		4	
14	1755-1930	610	Z/D	El	$3\frac{1}{2}$	$\frac{1}{2}$
15-18				O, Wx		
19	1723-1856	610	VMG	P, H	$1\frac{1}{2}$	
20-25				O, El, Wx		
26	2156-2314	621	VMG	N, H	1	
27	1924-1952	621	VMG	H	$\frac{1}{2}$	
Dec. 1-8				O, El		
9	1825-1922 2151-2256	630 647	VMG DOP	 Gr, H	1 	 1

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
10	1711-1824 1841-2039 2216-2247	647 " "	VMG DOP VMG	P, B P, B P, B	1 $\frac{1}{2}$	 2
11-13				O, B, Wx		
14	1858-2305	644	VMG	H, Ov	4	
15				O		
16	1900-2324	647	VMG	P, N, H	4	
17	1647-1941	647	VMG	H	3	
18				O		
19	2100-2241	658	VMG		$1\frac{1}{2}$	
20-31				O, Wx		
1972						
Jan. 1	1820-1829 2026-2031 2202-2204	670 " "	VMG " "			
2	1805-1825 1905-2348	670 "	VMG D/Z	 Gr, H	$\frac{1}{2}$ $\frac{1}{2}$	 4
3-9				O		
10	1843-2345	687	VMG		5	
11-13				O, El, Wx		
14	1651-1920 2005-2205	687 "	DOP "	Un Un		$2\frac{1}{2}$ 2
15	1738-1854 1900-1955 2001-2352	693 " "	DOP VMG DOP	 G 	 1 	1 4
16				O		
17	1620-1858 1906-2001	693 "	VMG DOP		$2\frac{1}{2}$ 	 1

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
18	1749-1811	693	VMG	El, B	½	
19	1658-1923 1930-2032 2146-2251 2252-0037	693 " " "	VMG DOP DOP VMG		2½ 1½	 1 1
20	1648-1717 1725-2219	693 "	VMG DOP	P	½	 5
21-23				O		
24	1654-0000	693	D/Z		½	6½
25	1800-2110 2120-2154 2156-2336	693 " "	DOP VMG DOP	C C C	 ½ 	3 1½
26-27				O, Wx		
28	1647-2356	707	DOP			7
29	1711-1930	707	DOP	C, N		2½
30	1721-0030	707	DOP	N		7
31	1706-0036	707	DOP	N		7½
Feb. 1	2120-2206	707	DOP	N		½
2	2308-2358	707	DOP	N		1
3-6				O		
7	1630-1830	724	DOP			2
8-15				O, El		
16	2335-0009	734	VMG	Un	½	
17	1659-1745 2257-2350	734 "	VMG DOP	Un Un	1½	 1
18-21				O, Wx		
22	1619-1911	748	VMG	P	3	
23	1607-1905	748	VMG	P, H	3	

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
24	1645-1751	748	VMG		1	
25	1750-2019	748	DOP			2
26-27				O		
28	2050-2252		DOP	Ov		2
29				O		
Mar. 1	1615-2200	760	VMG	Ov	5½	
2	1630-2051 2124-2313	760 765	VMG DOP	Ov Ov	5	 2
3				O		
4	1723-0057	760	VMG	N	6½	
5	1649-0035	760	VMG		8	
6	1617-2336	769	VMG	C, Ov	6	
7	1555-0024	769	VMG		8½	
8	1632-0024	769	VMG		8	
9	1605-2357	769	VMG		7½	
10	1640-0052	769	VMG		8	
11	1614-2006 2050-0027	769 "	DOP DOP			4 3½
12	1912-2210	769	VMG		3	
13				O, Wx		
14	1616-0047	776	VMG		8½	
15	1636-0044	777	VMG		8	
16	1545-1850 1850-2113 2126-0040	777 " "	VMG DOP VMG		3 3½	 2

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
17-18				O		
19						
20						
21-22				O		
23	1700-1741	787	VMG		½	
24	1730-0056	787	VMG		6½	
25	1800-2300	787	VMG			
26-31				O		
April 1	1750-1926		VMG			
2	1856-2001		VMG			
3-14				O		
15	1700-1853 1940-2346	829 "	VMG "		2 4	
16				O		
17	1630-1705 1804-2250	827 "	VMG "		½ 5	
18-19				O		
20	1700-0142	827	VMG		7½	
21	1545-0100	827	VMG	Ex	10	
22	1725-1836 1836-1907 1912-2100	827 " "	VMG DOP VMG	Gr	1 2	 ½
23-30				O		
May 1				O		
2	2330-0051		Z/D	P	1½	
3	2000-2200		VMG	C	2	
4				O		

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
5	1515-1718 1954-2105		VMG "		2 1	
6	1515-1928 1955-2103 2153-2250		VMG DOP DOP		4	 1 1
7	1636-2215		DOP			$5\frac{1}{2}$
8	1812-1910 2053-2124		VMG DOP	Ex Ex	1	 $\frac{1}{2}$
9	1520-1800 2012-2145		DOP VMG		 $1\frac{1}{2}$	$2\frac{1}{2}$
10	1600-2238		VMG		$6\frac{1}{2}$	
11	1640-1919		VMG		$2\frac{1}{2}$	
12	1530-1617		VMG	El	$\frac{1}{2}$	
13-16				O, El, Wx		
17	1630-0111	883	VMG		$8\frac{1}{2}$	
18	1715-2100	883	VMG	G	4	
19	1915-0020	883	VMG		5	
20	1630-1900	883	VMG	Ex	$2\frac{1}{2}$	
21	1545-1730	883	VMG	Ex	$1\frac{1}{2}$	
22				O		
23	1705-2400	883	VMG	Ex	$6\frac{1}{2}$	
24	1440-1852	883	VMG	G	4	
25	2100-2200	883	VMG	G	$\frac{1}{2}$	
26	1545-2340	895	VMG	G	8	
27	1750	895	VMG	G		
28				O		
29	2025-2138	895	VMG	Ex	1	

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
30	1515-1700 1830-2040	895 "	VMG "	G C	2 2	
31				O		
June 1	1500-0000	895	VMG	G	7	
2	1524	895	VMG			
3	1530-1600 1610-1720	895 911	VMG "		½ 1	
4-9				O, Wx		
10	2330	911	Z/D	P		
11	1620-2146	911	DOP	?		5
12	1350-2100 2100-2300	926 "	Z/D DOP		7	 2
13	1445-0045	926	VMG	G	10	
14	1500-1530 1530-1600 1615-0013	926 " 922	DOP VMG Z/D	G	 ½ 7½	½ ½
15	1600-1810 1810-2310	922 926	VMG "	G G	2 5	
16	1505-2100 2100-2350	928 930	D/Z VMG		2 3	4
17	1450-0100	930	D/Z	G	3	6
18	1550-1650 1650-2030 2030-2100 2100-2220 2220-2240	930 " " " "	DOP VMG DOP VMG DOP	G	 3½ 1½	1 ½ ½
19	1445-0040	930	VMG	G	9	
20				Wx		
21	1600-0130	930f	Z/D		8	2

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
22	1600-1740	930f	Z/D	G	1½	
	1815-1940	"	DOP			2
	1940-2230	"	VMG		2½	
23	1516-1630	933	VMG		1	
	1633-1640	930p	VMG			
24	1545-1640	930	VMG	G	1	
	1640-1700	"	DOP	G		
	1700-1900	"	VMG		2	
	1925-2000	933	"		½	
	2000-0130	930	"		5½	
25	1550-1952	930	Z/D		4	1
	2000-0100	933	VMG		5	
26	1530-1600	930/932	VMG		½	
	1600-1745	"	DOP			1½
	1745-1920	"	VMG		1½	
	1921-2246	"	DOP			3
	2246-2327	"	VMG		½	
	2327-0052	"	DOP			1½
27	1600-1623	930/932	VMG		½	
	1624-1704	"	DOP			½
	1705-1729	"	VMG		½	
	1729-1816	"	DOP			1
	1816-1927	"	VMG		1	
	1932-2055	"	DOP			2½
	2205-0118	"	"			3
28	1830-2100	932/930	DOP			2½
	2100-2130	"	VMG		½	
	2140-2230	"	DOP			½
29	1611-1750		DOP			1½
30	1545-1615	939	VMG		½	
	1618-1700	"	DOP		½	
	1700-2000	"	VMG		3	
	2054-0013	"	"		3	
July 1	1610-1753	939	VMG	G	2	
	1910-2229	Quiet	"		3	
	2236-2336	"	DOP			1

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
2	1520-1630 1700-1820 1820-0110	Quiet " "	VMG DOP VMG		1 7	1½
3	1520-1720 1917-2130 2130-0020	Quiet " "	VMG DOP VMG		2 3	2
4	1544-0100	Quiet	VMG		7½	
5	1600-1818 2040-2100	Quiet "	VMG "		2½	
6				O, El		
7	2330		VMG	Wx		
8	1630-1730 2100-0037	947 "	VMG "	G	1 3½	
9	1747-0200	947	VMG	G, C	8	
10	1600-1805 1810-1840 2030-0130	947 " "	VMG DOP VMG	G G	2 5	½
11	1600-2300 0050-0130	947 957	VMG "	G	7 ½	
12	1500-1530 1530-1630 1630-0100	947/957 " "	VMG DOP VMG		½ 8½	1
13	1600-1746 1757-1946	947/957 "	VMG DOP		2	2
14	1810-1830	957	DOP			½
15	1700					
16	1537-0130	958	VMG		10	
17	1530-0223	958	VMG	G	11	
18	1515-0130	958	VMG		10	
19	1500-1647 2100-0145	958 "	VMG VMG	El	2 4	

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
20	1911-2215	958	VMG		3	
21	1630-1745	958	VMG		1	
	1807-1830	″	DOP			½
	1830-2300	″	VMG		4½	
	2300-0000	″	DOP			1
22	1710-1800	958	VMG		1	
	1800-1838	″	DOP			½
	1838-0026	″	VMG		5	
23	1600-1730	968	VMG		1½	
	1830-2120	Poles	DOP			3
	2230-2330		VMG		1	
	2333-2400	968	DOP			½
24	1544-1610	958	DOP			½
	1628-1737	970	DOP			1
	1738-1809	″	VMG		½	
	1833-0138	972	″		7	
25	1450-1509	972	VMG	C	½	
	2328-0157	″	″		2½	
26	1530-1913	972	VMG		3½	
	1950-0049	″	″		5	
27	1530-0119	972	VMG	G	9	
28	1545-1720	972	VMG		1½	
	1720-1740	″	DOP			½
	1743-1802	″	VMG		½	
	1902-1934	″	″		½	
29				Wx		
30	1731-1800	976	Z/D		½	
31	1530-1613	976	VMG		½	
	1614-1644	″	DOP			½
	1716-1844	″	VMG		1½	
	2053-2145	″	″		1	
Aug. 1	1547-1637	976	Z	G	½	
	2046-0029	″	″		3½	
2	1544-1751	976	Z		2	
	2221-2311	″	″		1	

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
3	1658-1751 2336-0021	976 "	Z "	N N	1 1	
4	1614-2236	976	Z	G	6	
5	1606-1733 1834-1931	976 "	Z "	G, C	1½ 1	
6	1708-1846	976	Z	C	1½	
7	1550-2245	976	Z	C	5	
8	1515-1806 1904-1942 2145-2220	976 " "	Z " "	C, N	3 ½ ½	
9	1516-0047	976	Z	N	9	
10				Wx, El		
11	1644-1748	976	Z	N	1	
12	2230			S		
13	1540			S		
14	1544-0059	985	Z		10	
15	1833-0040	985	Z	N	6	
16	1556-0027	985	Z		9	
17	1539-0047	985	Z	N	9	
18	1538-0007	985	Z	N	8½	
19	1620-0050	985	Z	N	8	
20	1552-2255	985	Z	N	7	
21	1541-2320	002	Z	N	7½	
22	2031-2244	002	Z	C	2	
23	1523-2328	002	Z	N	8	
24	1820			S		
25	1930			S		

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
26	1547-2400	007	Z	N, C	8	
27				O, Wx		
28	1530-0045	007	Z	N	9	
29	1522-1700	007	Z	N, C	1½	
30				O, Wx		
31	1618-1726 1900-0115	007 "	Z "	 G	1 6	
Sept. 1	1526-2145	007	Z	N, C, El	6	
2				O, El		
3	1514-1730		Z	N	2	
4				O, Wx		
5	1558-2336	011	Z		7½	
6				O, Wx		
7	1602-1700	011	Z		1	
8	1708-1848 1955-2103 2116-2141	021 " "	VMG " "	G, R " "	1½ 1 ½	
9	1627-2201 2201-2344	021 "	VMG DOP	R	5½	 1½
10	1549-2320	021	VMG	B, R	7	
11	1604-2300	021	VMG		7	
12	1530-1600 1608-1725 1729-1902 1904-2150 2152-2314	021 " " " "	VMG DOP VMG DOP VMG		½ 1½ 1	 1½ 3
13	1519-1824 1830-0046 0047-0108	021 " "	VMG DOP VMG		3 ½	 6

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
14	1550-1720	021	VMG		1½	
	1739-2254	"	DOP			5
	2300-2341	"	VMG		½	
15	1627-1747	021	VMG	N, C	1	
	1813-2030	"	DOP			2
	2120-2205	"	VMG		½	
16	1535-1543	021	VMG			
	1620-1745	"	DOP	C		1
17	1526-1731	028	VMG		2	
	1731-1803	"	DOP			½
	1827-2015	"	"			2
	2019-2229	"	VMG		2	
18	1624-1706	036	VMG	B	½	
	1743-2058	040	"		3½	
19	1534-2031	040	VMG	B	5	
20	1635-1704	044	VMG		½	
	1704-2257	"	DOP			6
	2310-0102		VMG		2	
21	1529-1624	044	VMG		1	
	1632-1737	"	DOP			1
	1738-1758	"	VMG			
	1828-2009	"	DOP			1½
	2009-2219	"	VMG		2	

DATE	HOURS	REGION	MODE	COMMENT	VMG	DOP
Oct. 2	1611-1819		VMG		2	
Dec. 20	2204-2341		D/Z		½	1
21	1755-1850 1850-1915 2040-2300		Z/D DOP "		1	 ½ 2
23	1601-1656 1702-1849 1850-2341		DOP VMG DOP		 2	1 5
24	1747-1824 2150-2250		DOP VMG		 ½	½
30	2146-2324		VMG	N, B	1½	

D. Data: The Surveys

The movies represent only part of the data accumulated during the first year of operation. Between June 15 and September 22, 1972 (with the exceptions of Aug. 10 & 30, and Sept. 4 & 6, which were lost due to clouds) an effort was made to obtain daily photographs of each "interesting" region visible on the disk. The regions were spotted in H_α. When possible, the magnetograms were supplemented by simultaneous photographs on the East and West Cameras. The picture from the West Camera is nearly always center-line H_α taken with a 1/2-Å Hallé filter. The one from the East Camera could be most anything depending on the observing program for the day -- usually off-band H_α (with the Zeiss filter), but at times K-line, CN (λ3840), or even "white light" (continuum).

Each survey consists of photographs at ~10-20 different positions. Usually there are one, or perhaps two magnetograms at each. The filtergrams were taken in bursts of 5 or 10 at a time, from which the best could later be selected. The survey sequences have been spliced out of the main data and assembled in three separate rolls, each about 400′ long.

In preparing the data for examination, emphasis has been placed on the magnetogram-H_α pairs (which are consistently available from day to day). The supplementary data from the East Camera is largely unexamined.

From selected negatives, more than 2000 4″x5″ black and white prints were prepared. Of these, a number did not show enough activity to be conclusively matched in H_α-magnetic pairs (although in principle that could still be done by carefully examining the sequence in which the pictures were taken). The remaining 800 pairs have been assembled into a large 100 page album in which sequences representing the appearance of a particular region on successive days are arranged in vertical columns (Figure 14). A typical region is followed for ~10 days during its passage across the disk. Because the size of regions is quite variable, and does not always coincide with the ~6′ width of our field of view, several pairs of pictures are often required to fully represent a single region, particularly near disk center.

The survey album, beginning with McMath Region 11922 and ending with Region 12044, represents a total of about 62 different activity centers; that is, about half of those to which numbers were assigned. Nearly all of those missed were either weak plage at high latitudes, or emerging flux which failed to develop beyond the preliminary stages. Few of the spot groups indicated on the Mount Wilson drawings are absent from the survey.

The surveys are intended not only to portray the relatively well-known middle stages of development of active regions, but also to provide some insight into their less-well-under-

Figure 14: The Survey Album

A schematic representation of two typical pages. With the clocks in the upper left-hand corners, north is at the top, and solar rotation from left to right.

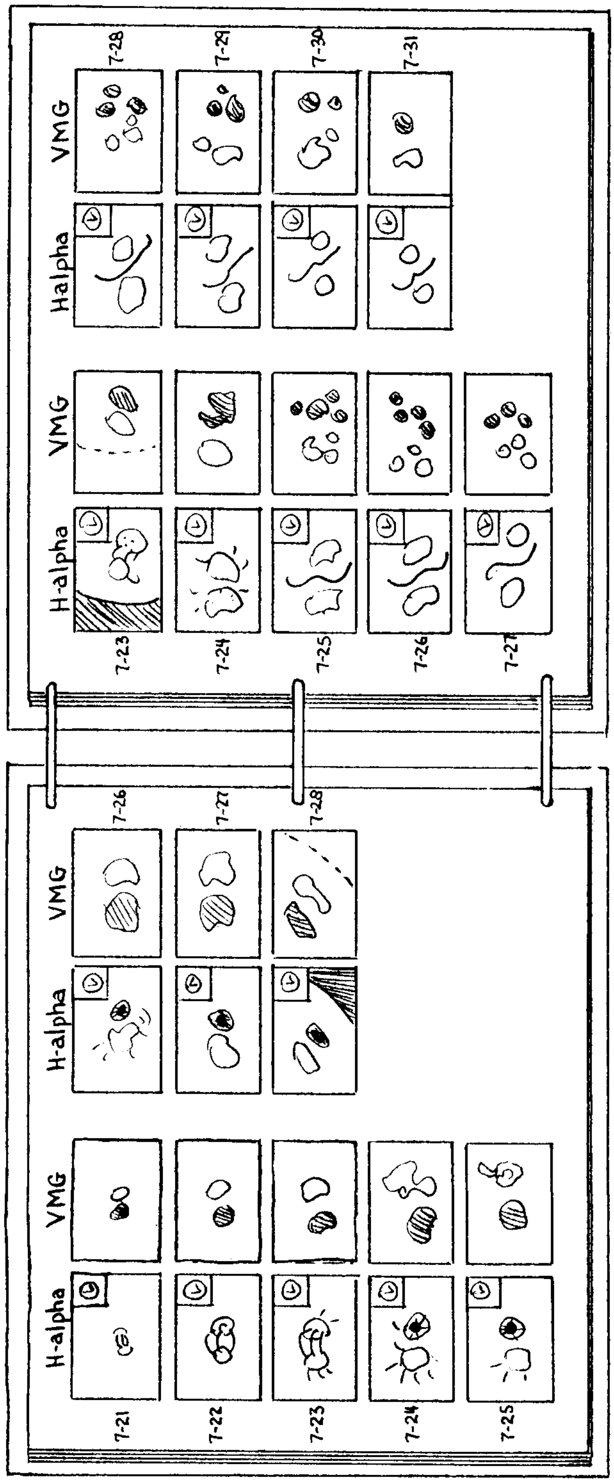

H-alpha
VMG
7-21
7-22
7-23
7-24
7-25
H-alpha
VMG
7-26
7-27
7-28
H-alpha
VMG
7-23
7-24
7-25
7-26
7-27
Halpha
VMG
7-28
7-29
7-30
7-31

Figure 14.

stood "birth" and "death" phases. It often seems as if most large regions are already well-developed when they rotate into view, yet a substantial fraction ($\sim\frac{1}{2}$) are, in fact, born on the visible disk. The album includes about 15 examples of the development of active regions (of varying sizes) essentially from the day of their first appearance, although in only two or three cases does there happen to be a magnetogram of the area prior to that (these are the few cases where the new activity erupted close enough to a previously existing region to have been accidentally included in the previous day's survey).

The "death" of a region is a much less precise idea than its birth, since the flux seems to disappear in a very gradual manner. In no case was a substantial bipolar region seen to suddenly disappear without a trace (although this did, occasionally, seem to be true of small portions of the field). There are about 10 examples of well-developed, moderate size sunspots (clearly visible in on-band H_α) breaking up into network-strength field. In two of these cases the spot subsequently re-formed in its old position after having been "diffused" for $\sim$1 day.

Due to the limited time ($\sim$15 minutes) available for each daily survey, it was not possible to carefully plan out what regions would be included. Thus the registration from day to day is somewhat erratic. In addition, no conscious effort was made to locate the areas which had been the site of activity on the previous rotation. No doubt, many portions of old remnant fields are included in the hundreds of as-yet-unclassified picture pairs, but usually the field is too spread out to get a very accurate impression of what it looks like anyway. For the long term evolution of fields, full-disk mangetograms, such as those produced at Kitt Peak, are far more useful.

Some regions, of course, remain intact, and easily identifiable even after several rotations. Of the 64 regions appearing in the album, a total of 11 appear on two or more successive rotations. Of these, 8 can be seen on three or more, and 4 of them are present for all four rotations covered by the data.

The results of the surveys are summarized in Table II.

Table II

The accompanying list indicates the extent of the survey data. Each region appearing in the album is indicated, in the first column, by its McMath Calcium Plage number; in the second, by the span of days for which coverage was included; and, in the third, by the actual number of days, during that period, for which observations were made. The original album is in the Big Bear collection at Caltech.

REGION	COVERAGE	DAYS	COMMENT
11922	6/15-6/18	4	
11924/5	6/16-6/19	4	
11926	6/15-6/19	5	
11927	6/16-6/22	7	
11928	6/16-6/27	12	
11929	6/16-6/24	5	
11930	6/16-6/28	12	
11931	6/16-6/17	2	
11932	6/19-6/28	5	
11933	6/21-7/2	10	
11936	6/24-7/2	9	
11938p	6/27-6/30	4	
11939	6/27-7/6	10	
11940	6/26-7/7	11	
11944	6/29-7/5	6	
11945	7/1-7/10	10	
11947	7/2-7/15	14	
11949	7/4-7/14	11	
11951	7/3-7/12	10	
11953	7/8-7/19	12	
11954	7/8-7/15	8	
11954p	7/9-7/18	9	
11956A	7/13-7/23	9	

REGION	COVERAGE	DAYS	COMMENT
11956B	7/18-7/24	7	
11958	7/12-7/24	12	
11963	7/18-7/27	10	
11965	7/18-7/28	12	
11968	7/23-7/31	9	
11970	7/23-8/4	13	
11972	7/25-7/30	7	
11976	7/28-8/9	13	
11977	8/1-8/9	9	
11979	7/28-8/9	13	
11981	8/4-8/14	6	
11985	8/9-8/20	10	
11986	8/12-8/19	8	
11989	8/11-8/19	9	
11992	8/13-8/23	11	
11993	8/14-8/25	12	
11994	8/15-8/25	11	
11999	8/19-8/29	11	
12001	8/19-8/29	11	
12002	8/21-8/29	9	
12006	8/24-9/3	10	
12007	8/25-9/5	10	
1200	8/26-8/29	4	
12010	8/28-9/3	5	

REGION	COVERAGE	DAYS	COMMENT
12011	8/26-9/9	11	
12014	8/31-9/5	4	
12016	8/31-9/10	8	
12021	9/7-9/16	11	
12023	9/7-9/11	5	
12025	9/7-9/14	7	
12026	9/7-9/13	6	
12028	9/9-9/19	10	
12029	9/14-9/21	8	
12030	9/11-9/20	10	
12035	9/14-9/18	5	
12036	9/15-9/21	7	
12039	9/16-9/21	6	
12040	9/16-9/21	6	
12044	9/20-9/21	2	

E. Some Problems

While results obtained by the image cancellation technique give a generally reliable impression of the surface magnetic and velocity fields, they are not infallible. Some of the defects, such as noise, scratches, and misregistration, are too obvious to merit discussion, but others are not. We will consider a few of them here.

1. Filter non-uniformities:

In general, the most serious problems are encountered in association with Doppler cancellations, and of these, the most obvious is the so-called "Doppler gradient" -- a shading effect which causes part of the screen to appear light and part dark, as if one large portion of the surface were continually rising, while another were falling. This effect is caused by tiny non-uniformities in the filter bandpass. As the reader will recall, we are, in the Doppler mode, trying to detect shifts as small as 1/50 or even 1/100 Å. If uniform Doppler sensitivity is to be achieved over the whole field, the filter bandpass has to be centered on the line to within that tolerance. While it is easy to do this at any one point, it is virtually impossible to do it over the entire field. Even if the calcite faces were perfectly flat and parallel, which they are not, such relatively minor effects as the variation in angles between the paths of on- and off-axis rays, or even solar rotation would be sufficient to create gradients. Each mistuning of the filter is equivalent to a "real" shift of the line in the opposite direction. Since we place the filter directly in front of the camera, where it is nearly in focus, the slightest non-uniformity appears as a splotchy pattern of apparent background motion, against which the true photospheric velocities are seen.

One might think that the obvious solution would be to slide the filter up the bench to where it is out of focus. In practice, however, we have found that this gives very poor results. The gradient goes away, but so does the signal. For unknown reasons, neither the filter nor the KDP likes to work at the narrow point in the beam. The gradients _can_ be minimized by rotating, twisting, and tilting the filter until a "good" part of the aperture is found, but they cannot be entirely eliminated. Usually one is happy if as much as, say, 2/3 of the field shows a reasonably uniform signal. On most of the Doppler movies there are obvious "dead spots" around the edges where the bandpass is simply too far off the line to give a useable signal.

Naturally, large non-uniformities in bandpass will have some effect on magnetograms too, but the effect there is considerably less important. Essentially it means nothing more than that different parts of the line wing are being used to form the magnetogram in different parts of the field, so that there will be slight variations in sensitivity from one point to the next. In the double bandpass mode these variations are particularly small, for as the slope and light level get worse in one wing, they tend to get better in the other.

At any rate, the variations in magnetic sensitivity caused by the Doppler gradient should not be much worse than those caused by the normal background Doppler wiggles which occur all over the field anyway, and are not compensated for in the filter technique. Those, if serious, would cause the apparent strength of network magnetic fields to show a 5-minute oscillation (as different parts of the line are used), and this, as far as we know, has not been seen.

2. Brightness variations:

Our sensitivity to both Doppler and magnetic signals is affected by variations, across the aperture, in light level, whether of solar or instrumental origin. An extreme case is the umbra of a sunspot. As far as the Plumbicon camera is concerned, the umbra is black, and the cancellation there is of essentially zero volts versus zero volts. Hence, on all our movies the centers of large spots appear as areas of flat unchanging gray. While the penumbras do have enough light to produce a useable signal, the field strength seen there is presumably considerably less than it would be if they had normal photospheric brightness. Thus, when on high resolution videomagnetograms one sees such things as spoke-like magnetic filaments in the penumbra of large spots it is not entirely obvious to what extent that is real phenomenon and to what extent it merely represents an essentially uniform field whose apparent strength is being modulated by an underlying brightness pattern. Photographic cancellations, incidentally, are less vulnerable to this problem because the response of their emulsion is more nearly logarithmic.

As in the umbras of spots, the magnetograph will also register zero signal if other objects obstruct the beam so as to block light from the camera. This happens, for example, when the field stop or the electronic blanking bar gets in the way. Usually this condition is obvious, but because the field stop is round, it can easily be confused with the solar limb.

Less obvious vignetting is caused by the pre-filter. Depending how it is tilted, there can be a loss of light (and signal) around the edges of the picture.

3. Line weakenings:

Since low light levels reduce the sensitivity, one might think that the typical 10-20% enhancement of brightness in the photospheric network would enhance the signals found there. This increase in brightness is, however, only with respect to the normal absorption level of the line, and is actually due mainly to a reduction in its intensity. Since the line is both shallower and broader, the sensitivity is less than one might expect on the basis of a calculation using the undisturbed profile (as in Part II).

An additional source of broadening is the Zeeman splitting itself. In areas with magnetic fields, the normal line weakening is compounded by the displacement of the polarized components. For magnetic work, it is this splitting from which the signal is derived; but for Doppler work, it is simply another effect tending to wash out the line profile, and reduce sensitivity. Thus, it would not be surprising to see magnetically disturbed regions exhibit a somewhat smaller amplitude of oscillation than undisturbed ones.

Even with a magnetically-insensitive line, some loss in Doppler sensitivity is to be expected (Frazier, 1974).

4. Magnetic leakage:

A more serious kind of cross-talk between magnetic and velocity signals can occur as a result of instrumental polarization (due, for example, to beam splitters and to reflections off mirrors). If the telescope optics have a tendency to convert the circularly-polarized Zeeman components into a linear form (by acting as a quarter-wave plate), or simply transmit one better than the other, then the Doppler analyzer (Figure 5), the first element of which is an ordinary polaroid, will tend to pick out one of these preferentially. Figure 15 indicates schematically how this can convert a Zeeman-split line into one whose center of gravity is displaced,

Figure 15: An explanation of magnetic leakage

A Zeeman-sensitive line develops an effective Doppler shift in magnetically disturbed areas when passed through an optical system which preferentially transmits one circular polarization.

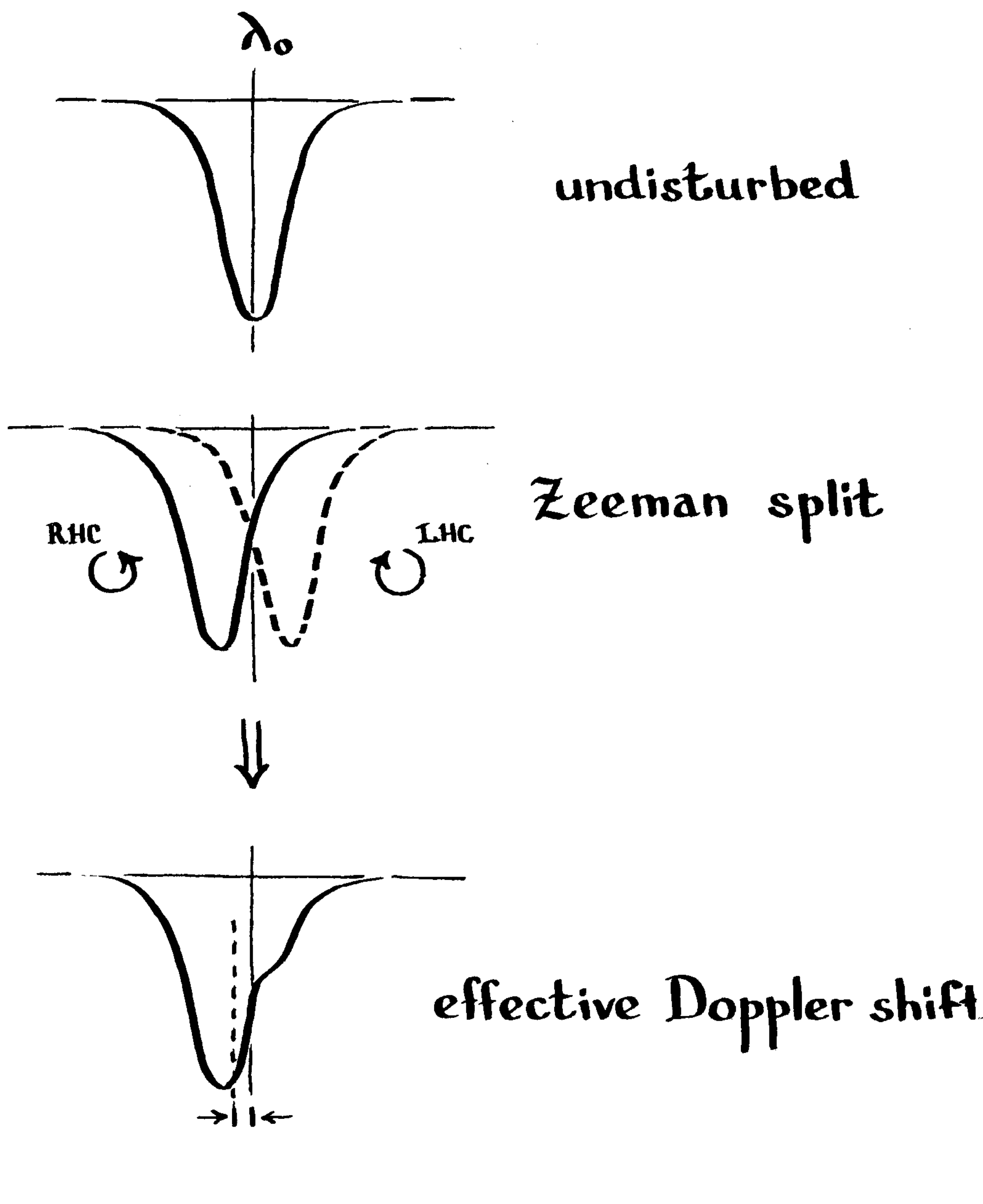

λ_0
undisturbed
Zeeman split
RHC
LHC
effective Doppler shift

Figure 15.

as if by a Doppler shift.

On many of the early Doppler movies, this effect (whose importance was not at first recognized) is present. It causes magnetic features of one polarity to appear to be rising, while those of the opposite polarity seem to be sinking. The sign of the effect can be reversed by rotating the circular polarizer 90°, and essentially eliminated by centering the polaroid between the two "bad" positions.

The problem could be avoided entirely either by using a non-Zeeman-sensitive line or by being more careful to avoid reflections in the beam.

5. Effects of instrumental polarization on magnetograms:

If the telescope does transmit one circular polarization better than the other, then the whole image will have a slight magnetic bias of one sign or the other. This will affect the zero level, and, for a filter used in the single bandpass mode (such as the Zeiss during 1972), cause a bit of the live picture to leak through on top of the true signal. Since almost all of the magnetograms show a nice flat background gray level, this is evidently not much of a problem, although in truth the only really significant brightness variations in the photosphere (ie., spots and faculae) occur in places where there is a substantial real signal anyway, so that it would be very difficult to tell whether or not the live picture were leaking through. The fact that on occassion the gray level in the sky and in the umbras of spots appears different from that defined by the general quiet photosphere might be due to this effect. Most background variations have other causes, however. The bull's-eye pattern of "ripples" seen on some of the frames is caused by the KDP, and the top-to-bottom shading, when present, is due to a faulty setting of the compensation circuits.

Instrumental polarization should not affect magnetograms made in the double bandpass mode, since in that case the polarization excess is sampled in both wings of the line and has to be opposite in order to produce a blinking.

6. Polarity biases:

On some of the magnetograms there is a clear tendency for one polarity to be displayed more favorably than the other, and on the movies for one polarity to fade relative to the other. While such biases can easily arise either electronically or photographically, they often seem to have something to do with trying to operate the filter at an incorrect temperature where the bandpass is not correctly centered on the line. The exact origin of the effect is unclear, but it presumably has something to do with instrumental polarization (which would allow the two polarities to behave unsymmetrically) coupled with the improper use of the filter.

Ordinarily, temperature shifts simply reduce the overall magnetic sensitivity, or, on Doppler movies, cause the zero level to fluctuate.

7. Doppler zero level:

The shade of gray corresponding to zero field is easily recognized on most magnetograms because the fields occur in the form of isolated patches seen against a neutral background. On Dopplergrams, the zero level is not so obvious because the whole picture is covered by a mottled pattern of intensity variations, both real and instrumental.

No matter how the zero level is determined, it is clear, on the movies, that it changes. This is because the filter temperature changes. A 0.1° C. fluctuation is sufficient to shift the bandpass by about .03 Å (at $\lambda 5324$), equivalent to a velocity of ~ 1.7 km/sec. If the temperature gets too far off, the cancellation will become seriously imbalanced (because the transmission peaks are no longer situated symmetrically in the wings), and as a result will begin to look either like the live picture or like a negative of it (the cancellation, in a sense, becomes continuum versus line rather than red wing versus blue wing). It is very difficult to control the filter temperature accurately enough to void these effects. Even a changing pattern of sunlight falling on the filter can upset the cancellation. When the operator tries to correct for the error he usually overshoots, and then the movies oscillate, over periods of a few minutes, in and out of the balanced Doppler mode.

8. Strong fields:

As explained in Part II, the strict proportionality of signal to field strength, or velocity, depends on ones being in the linear part of the line profile. The signal will not increase indefinitely. Roughly speaking, the maximum signal is obtained when the core of the line is shifted to that point in the wing at which the filter is operating. For the 1/8 Å λ5324 filter, where the two bandpasses are ±1/16 Å from the core of the undisturbed profile, this takes either velocities of about 3 km/sec, or magnetic fields of about 3000 gauss. Stronger fields, if encountered, would actually produce smaller signals. Thus there is a slight ambiguity as to whether a particular shade of gray corresponds to a field of moderate strength, or to a very strong one. In practice this is not too important, since most fields are simply regarded as being either "black" or "white", and under no circumstances (except if the line appeared in emission) could the apparent sign of the signal reverse.

9. Electronic saturation:

Since neither the light level nor the response are perfectly uniform over the target area of the camera, it is quite possible for the video signal to be saturated (featureless white) in some parts of the picture, while it is normal in others. When the signal is saturated, the slight intensity variations associated with magnetic "blinking" will have no effect on the signal level, and as a result those areas will be represented on the cancellation by patches of featureless gray. The effect is similar to the loss of signal in the umbras of large spots, except that it occurs in bright areas of the field rather than dark.

On occasion, when viewing the movies the fields over a portion of the screen will suddenly disappear, for no apparent reason. Electronic saturation may be the problem, and the live picture, as recorded at the beginning of the run, should be examined to see if it is possible. A particularly prominent example is the disappearance of black network fields in the movie for May 10, 1972.

If the live picture is on the verge of saturation, small variations in the background light level can cause large changes in apparent field strength. The cancellations will have a "busy" appearance, with signals showing rapid, small-scale fluctuations.

10. Geometric distortions:

In viewing the video cancellations, and, in particular, in trying to correlate them with other data, it is important to keep in mind that the height, width, and linearity of the pictures are all subject to electronic adjustment, and can, at times, be quite far off. Even under the best of circumstances it may be impossible to accurately register a videomagnetogram with a direct photograph of the same region.

Summary:

The interpretation of magnetic and velocity data obtained by the image cancellation technique is complicated by the possible failure of the process to completely compensate for such effects as: brightness and temperature fluctuations in the photosphere, "wedging" and temperature errors in the filter, cross-talk between modes, electronic losses, and general uneveness of response. As a rule the consequences of these errors are most serious in the Doppler mode, where false signals can arise, and where there is no obvious background against which the signs of individual features can be compared. Magnetograms are affected mainly in the sense that signals can occasionally be lost due to saturation effects.

While it is important that one recognize these problems it is also possible to make too much of them. Though imperfect, the video results are no worse than others. In a few of the more sophisticated systems (such as at Mount Wilson), it is possible to reduce the effects of local Doppler shifts on magnetic sensitivity by re-centering the line at each point, and to eliminate most of the effect due to brightness variations by boosting the gain in areas where the light level is low -- but these are small effects.

The videomagnetograms give a basically reliable impression of the shape and structure of the magnetic fields. Results obtained from them, in studying the lifetime, evolution, or even the relative strength of various features, will not be totally erroneous. On Dopplergrams, the basic impression regarding the sizes and periods of localized features will be fundamentally correct, even if larger patterns of motion are obscured by gradients and uncertainties in zero level.

F. <u>Calibration</u>:

The shade of gray corresponding to a particular field strength, or velocity, depends not only on the field strength, but also on the condition of the filter (temperature, tilt, etc.), the condition of the sky (haze, turbulence, etc.), the adjustment of the electronics (gain, black-level, etc.), the contrast of the monitor display, and the development of the film. While it would be nice to have a kind of step-wedge calibration incorporated into the display format, it is difficult to see at what point in the processing it could be inserted, and yet maintain a meaningful relation to field strength. What is needed to calibrate the system is a way of determining, empirically, its response to a known amount of circular polarization (in the case of magnetograms) or to a known spectral shift (in the case of Dopplergrams).

Only for the Doppler cancellations is such a calibration possible. Because of solar rotation, the East Limb appears always to move towards us at about 2 km/sec, while the West appears to move away, at the same apparent speed.

Thus, with the normal polarity convention, a Dopplergram made in the East will be generally light, and one made in the West generally dark, the difference between the two corresponding to a velocity of about 4 km/sec. The problem with this is that the light level is low at the limb, so that the sensitivity there is lower than normal. Also the shift is a little large for calibration purposes. It is probably about as accurate to judge the strength of velocity features in relation to the average oscillating background (which has peak amplitudes ~1 km/sec).

The calibration of magnetic signals is more difficult. Roughly, the quality of the Doppler signal gives an indication of magnetic sensitivity in the sense that if the Doppler signal is strong and well-balanced, the magnetic signal will also be good, whereas if it is weak or un-balanced (as it is at the limbs), the magnetic signal will also be weak (unless the filter temperature is re-adjusted); but it cannot be used in any quantitative way: the light level is different, the sensitivity to spectral errors is defferent, and even the contrast with which the monitor is photographed is usually different.

While the uniformity of magnetic response can easily be examined by changing the telescope pointing so as to display a particular "test" feature in different parts of the screen, no standard exists for the calibration of its absolute magnitude. Lacking an internal standard, one can, of course, attempt to compare the video data with that generated by other magnetographs. Comparison with Mount Wilson magnetograms is difficult because of the difference in resolution. Prominent network field points usually seem to correspond to "10 gauss" features. Weaker ones are either missed or lumped together into extended "5 gauss" patches. "2 gauss" plots (Howard, 1974a) seem to indicate a network more extensive than that seen on the video data. 2 and 5 gauss are, of course, the effective field strengths averaged over a 17" aperture. On the videomagnetograms, the characteristic size of the network elements is more like ~4-5". Their effective strength, therefore, is around 50-100 gauss (rather than 2-5). The actual strength could be much higher if, as seems likely, they are still unresolved. Thus, although the videomagnetograph is inherently less sensitive than a more sophisticated photoelectric system, the loss is recovered through improved spatial resolution, and since solar fields are concentrated into isolated patches, the results are much the same.

For a diffuse field, should one exist, the detection threshold, at the point where the signal is just barely distinguishable from random fluctuations in the background gray level, is probably in the range 10-50 gauss.

G. <u>Future Projects: H_α and λ6103 Doppler Movies</u>

Doppler movies are possible only with double-bandpass filters and during the period described here, such work was confined to the Fe I line, λ5324. The discovery that the Zeiss can be converted to double-bandpass operation (Appendix I) raises the possibility of making Doppler movies in H_α and in λ6103 as well. After flipping the filter over (as shown in Figure A1-5), one would simply insert an appropriate circular polarizer into the beam ahead of the KDP. The main problem is that the light level, particularly at H_α, is already rather low, even with the filter at its "1/2 Å" setting, and the extra polarizer would reduce the light level at least by a factor of two more. One solution would be to use a smaller image and a faster beam, but that is likely to aggravate the Doppler gradients, which are already present at the normal speed. A better solution might be to use the KDP and filter in conjunction with an ordinary camera, capturing the Doppler signal on film for future processing.

If the Plumbicon is used, one must be careful to include enough heat absorbing glass to block out the infra-red leakage, which can be rather serious with the Zeiss.

H. <u>Future Projects: Transverse Field Measurements</u>

Just as a line-of-sight magnetic field is revealed by the presence of circular polarization, a transverse one is revealed by the presence of linear polarization. The transverse Zeeman effect, acting upon a normal Zeeman-sensitive line, creates two symmetrically displaced components, polarized perpendicular to the field, leaving a residual, unshifted core, polarized parallel to the field.

Measurements of transverse fields are unpopular for several reasons. The signal is only half as great as for a comparable line-of-sight field. Instrumental effects can polarize the entire image, making it difficult to distinguish real from false signals. The display is ambiguous (the patches of black and white should really be arrows, but the magnetograph cannot tell their heads from their tails). The signal is greatest near the limb where observation is most difficult.

Despite these many problems, the detection of transverse fields is still a subject of considerable interest. Their mere presence would be of significance, particularly in connection with young emerging flux, and in H_α one would expect to see substantial transverse fields accociated with those areas in which the fibril structure seems to lie along the surface.

A device such as the videomagnetograph is ideally suited for making the differential measurements needed to detect and display linear polarization. In fact, the present setup can easily be converted to this application by making a few simple modifications to the analyzing apparatus placed in front of the filter. Figure 16a shows one such scheme, in which a flipped over circular polarizer is placed behind the KDP. The KDP, acting as a ±1/4-wave plate, converts two initial linear polarizations (at 45° to its own axes) into opposite circular polarizations. The following mica quarter-wave plate (the first element of the reversed circular polarizer) converts them back into a linear form. The polaroid (which could be the entrance polaroid of the filter) passes one. The direction of the original polarization corresponding to that which will ultimately be transmitted is determined by the orientation of the KDP, and can be reversed by reversing the voltage applied to it. Thus the combination of KDP plus circular polarizer acts as a kind of electronic gate, admitting first one linear polarization, then the other. If the filter is tuned to the core of the line, the "magnetogram" will represent polarization differences in the core; if it is tuned to the wing, it will show differences in the wing (which should be the same as those seen in the core, except with the sign reversed).

The light level available for transverse field measurements could be considerably improved by using the filter in a double-bandpass mode. Essentially, this involves nothing more than removing the entrance polaroid (Figure 16b). The mica quarter-wave plate would then be oriented so that one of the exiting linear polarizations is transmitted in the

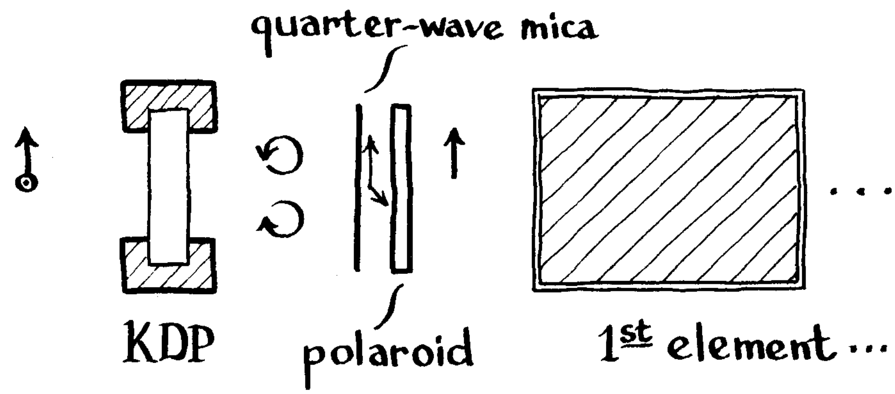
Figure 16: The detection of linear polarization

The basic magnetograph system can be converted to the detection of linear polarization in either of two ways. In both schemes, a mica quarter-wave plate is placed behind the KDP. Initially linear polarizations are converted into a circular form by the KDP (acting as a plus or minus quarter wave plate), and then back into the linear form by the mica. On leaving the final quarter-wave plate, however, the orientations are "rotatable": that is, an initially vertical polarization can come out either vertical or horizontal depending on the polarity of the KDP.

In the single-bandpass mode, the mica quarter-wave plate is followed by an ordinary linear polaroid. The polaroid axis must be at 45° to the mica axes, so that first one and then the other initial linear polarization is admitted to the filter. By suitably orienting the filter with respect to the polaroid, the polarization can be measured at any selected point in the filter bandpass.

If one is willing to sacrifice ones's ability to precisely define the operating wavelength, a double bandpass mode, in which one compares the polarization in the wings of the line with that in the core (Figure 16B) is possible. The transmission patterns interchange when the sign of the voltage applied to the KDP is reversed.

A. Single bandpass mode



B. Double bandpass mode

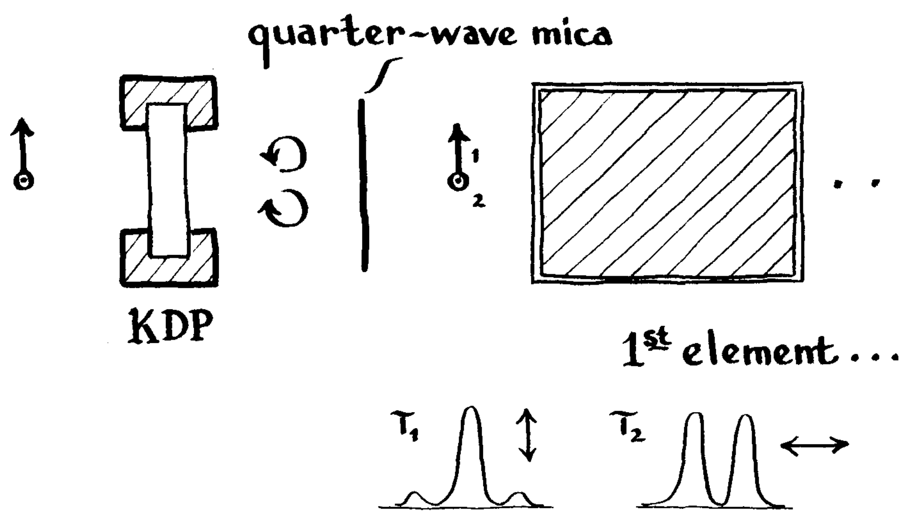


Figure 16.

core of the line, while the other is transmitted (simultaneously) in the two wings. The image is the sum of the two. Reversing the voltage on the KDP interchanges the polarizations, and the difference between the two images is the signal.

Presumably the most interesting results would be found in the core of H_α, but several problems are encountered in trying to use that line for magnetic work. In the first place, because the line is so broad (and yet the splitting no larger than that for any other line) the sensitivity is far less than we are accustomed to. In addition, the line is more "contrasty" -- that is, there are strong small-scale brightness variations, causing the sorts of misregistration problems usually encountered only around spots to appear all over the field. Thus one is in the position of trying to pull a smaller-than-normal signal out of larger-than-normal noise. Better results would probably be obtained at $\lambda 6103$ or $\lambda 5324$.

The effects of instrumental polarization, which might confuse the interpretation of the results, can be eliminated by being careful to orient the KDP in such a way that the two directions of polarization being analyzed are at 45° to the axis of the instrumental effect. It would be better, however, to avoid the problem entirely by using a "straight through" bench on the spar, with no beam splitters or mirrors.

It is in this respect, particularly, that the light, portable videomagnetograph excells. More sophisticated systems, because of their mechanical complexity, are almost invariably fed by reflecting coelostats, and have far more **serious** polarization problems.

The transverse field detection schemes, and the double-bandpass Doppler modes, can, of course, be used visually, as well as with the complete system. With the KDP rigged to a hand switch, the image can be examined as its polarity is modulated. The H_α Doppler signal would presumably be quite obvious, but the magnetic blinking due to transverse fields could be very subtle.

None of these schemes has yet been tested carefully enough to give definite results. There is reason to believe that the linear polarizations might be even less than expected. Nonetheless, a careful study of the appearance of sunspots (in the transverse mode) as they move across the disk would do much to enhance our understanding of the interpretation of normal magnetographic recordings, particularly as regards the visibility of magnetic features close to the limb.

APPENDIX I: BIREFRINGENT FILTERS

The success of the birefringent filter (Lyot, 1933; Evans, 1949) is based entirely on the properties of polarized light; in particular, on the principle that no light can pass through a pair of crossed polaroids unless an optically-active substance is placed between them so as to alter its state of polarization. If this activity is a function of wavelength, then certain colors will be transmitted, either partially or fully, while others will be rejected.

When a piece of calcite, or a similar birefringent crystal is placed between the polaroids, the transmission pattern is particularly simple (Figure A1-1). If the polaroids are cemented on at 45° to the crystal axes, it will be a cosine-squared pattern in wavelength. The position and sharpness of the peaks are completely determined by the length of the crystal: the longer it is, the sharper and more closely spaced will be the peaks.

Since the difference in indicies is small, even for the most active substances, relatively long crystals are required in order to achieve narrow bandpasses. An 1/8 Å calcite element, for example -- meaning one which has peaks every 1/4 Å in the green -- requires a crystal about two inches in length. Not only are such crystals expensive, but they are

Figure A1-1: A tunable 1/8th A birefringent element

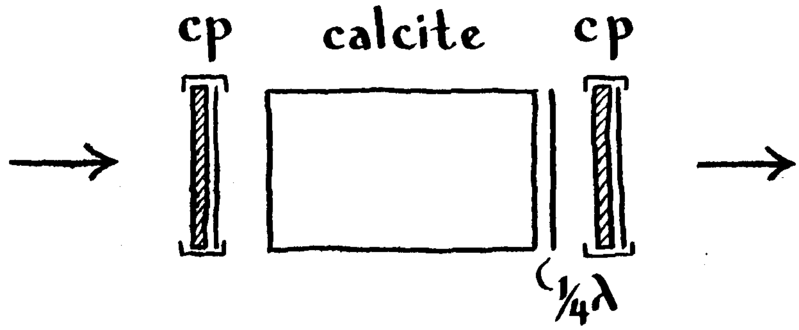
The basic tunable birefringent element consists of a calcite block sandwiched between circular polarizers. n_1 and n_2 refer to the indicies of refraction along the principal axes (in the plane perpendicular to the optical axis). For calcite, $n_1 - n_2 \approx 0.17$ (Evans, 1953). ϕ represents the continuously variable "phasing" obtainable by rotating the exit polaroid. The narrowest elements are often split into two or more pieces separated by half-wave plates so that the filter can accept rays at a larger variety of angles. The wave plate axes are always at 45° to those of the crystal.

Birefringent elements are normally named according to the half-width of their transmission peaks. Thus a "1/8th Å element" will have peaks every 1/4 Å. A simple algebraic manipulation of the indicated formula will show that the "width" of an element is related to its length by:

$$\Delta\lambda = \frac{\lambda^2}{2\ell(n_1 - n_2)}$$

Thus for calcite a 1/8 Å bandpass requires a piece nearly 6 cm. in length.

The birefringent element:



$$T = \cos^2\left[\frac{\pi \ell (n_1 - n_2)}{\lambda} + \phi\right].$$

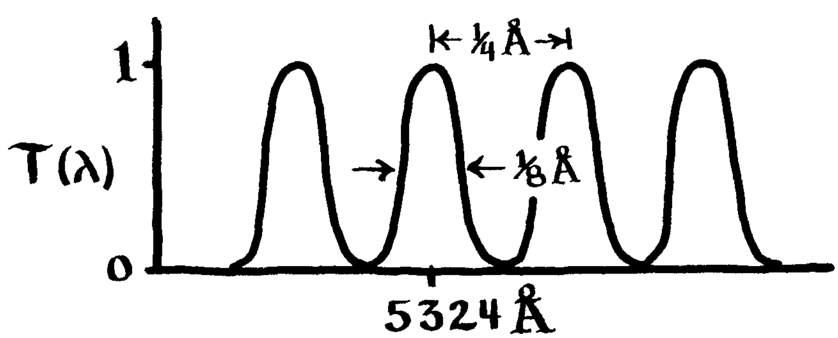


Figure A1-1.

also quite sensitive to the angle of the light, needing a nearly-parallel beam if they are to function properly. Although both of these problems can be to some extent avoided by cementing together a series of shorter elements with waveplates in between, elements narrower than about 1/8 Å are seldom actually made.

A 1/8 Å birefringent element, all by itself, is, of course, of very little value, since in addition to the desired wavelength it transmits numerous "sidebands" equally well. Within the window of a 10 Å prefilter, for example, there would be some 40 peaks, only one of which is wanted. The usual solution is to combine the 1/8 Å element with other broader birefringent elements, which transmit the central peak but reject one or more of the secondary ones.

The most efficient system is to use a series of crystals each of which is half the length of the preceding one (Figure A1-2). Since each will reject half the sidebands transmitted by the previous ones, some five or six such additional elements would be needed in order to clean up the 40 unwanted peaks in our example.

In order for this solution to be effective, however, it is necessary that each element be precisely tuned to one chosen wavelength. For the sort of elements which we have been describing, this is rather difficult, since the position of the cosine-squared transmission pattern is fixed by

Figure A1-2: Filter construction

A complete birefringent filter can be obtained by stringing together a series of elements of varying length. Ideally, each element should be half the size of the preceding one, so that it has transmission minima where the others had maxima. The figure indicates graphically how the various transmission patterns combine to suppress all significant peaks within a considerable distance of the main one to which the filter is tuned. Wavelengths very far from the central peak are suppressed by means of a narrow-bandpass interference filter used in conjuction with the birefringent elements.

Filter construction:

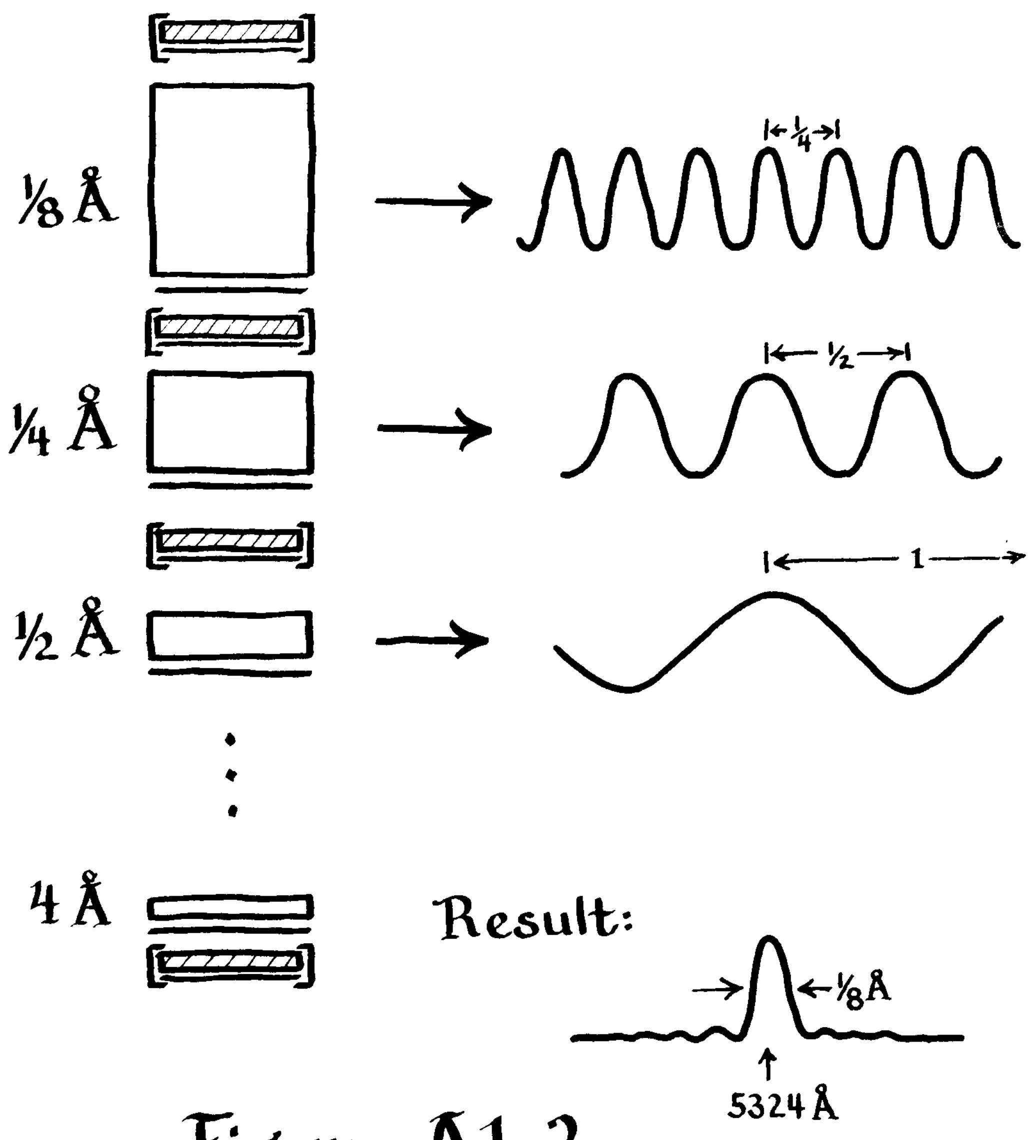


Figure A1-2.

the length of the crystal, and cannot be moved except by changing its temperature. A complementary transmission pattern could be selected by rotating the exit polaroid 90°, but short of that, any other modification in the position of the exit polaroid would serve only to degrade the overall performance, since the intermediate wavelengths emerge from the crystal with an elliptical polarization. Fortunately, the basic elements can be made tunable by a relatively simple modification.

In particular, if one adds a mica quarter-wave plate to the end of the calcite, cementing it on at 45° to the crystal axes, then this will have the effect of converting all the emergent radiation into a linearly polarized form. Although it may be a bit difficult to see how this works in general, it is easy to appreciate that the few wavelengths which would emerge linearly polarized anyway will be coincident with one or the other of the waveplate axes, and hence be unaffected by its presence. The wavelengths that would normally leave the crystal with a circular polarization, will be converted into a linearly-polarized form by the waveplate, and at 45° to its axes -- that is, in between the positions corresponding to the other wavelengths. In fact, all of the wavelengths for which the mica acts as a quarter-wave plate will be converted into a linear-form, the angle of polarization simply rotating with wavelength. Under such circumstances, the exit polaroid can be made to select any desired wavelength by suitably adjusting its angle -- in effect, rotating the exit polaroid slides the transmission pattern to any desired position.

The same effect can be achieved at the entrance end by cementing a quarter-waveplate onto the front of the crystal -- in which case rotating the entrance polaroid would slide the transmission pattern -- but this is not generally done, since it is sufficient to be able to tune an element from one end. Indeed, since the successive elements share polaroids -- the polaroid which acts as the exit polaroid for one element generally also acts as the entrance polaroid for the next one -- it is actually undesirable to have the element tunable from both ends, for then that would mean that turning a single polaroid would affect two elements at once.

A much simpler, yet equally effective, operation can be obtained by changing these inter-element polaroids into circular polarizers (by cementing mica quarter-waveplates to their back sides). The elements function just as efficiently when fed by circularly-polarized light as when fed by linearly-polarized light, but with the circular polarizers, one can tune the preceding element at will without affecting the following one.

Narurally, most of the elements are placed deep within the filter's thermal housing, and cannot be easily altered.

These are generally adjusted prior to assembly so as to have their transmission peaks centered on some desired line. The tunability of the first and last elements can, however, be retained, simply by placing their tuning polaroids in a position outside the filter package where they can be adjusted manually.

The double bandpass filters used with the videomagnetograph exercise this option, placing the thickest element (the one which gives the narrow, high-frequency, component to the transmission pattern) at the front, and leaving it bare except for an added quarter-wave plate. By turning an ordinary linear polaroid in the beam ahead of the filter, one can then slide the transmission peaks of this narrow-bandpass element relative to the fixed broader profile defined by the rest of the filter. As illustrated in Figure A1-3, there are two orthogonal positions which will give symmetric transmission peaks displaced slightly in wavelength. If the spacing of these peaks is correct (the spacing being determined by the length of the calcite blocks), they can be made to fall in opposite wings of a spectral line.

Rather than physically rotating a polaroid in the beam, the incoming polarization can be switched with the KDP. This is accomplished by feeding the KDP with circularly-polarized light, either created on the sun (Zeeman mode) or artificially produced (Doppler mode), and operating it as a plus or

Figure A1-3: The double bandpass mode

An ordinary birefringent filter can be converted into the double bandpass mode by removing the entrance polaroid and replacing it with a quarter-wave plate at 45° to the crystal axes. Orthogonal entrance polarizations will then have complementary transmission patterns, as shown. For a suitable choice of orientation, one bandpass will be primarily in one wing of the line, while the other bandpass will be primarily in the other wing. The spacing between the peaks is equal to the half-bandwidth of the narrowest element. Thus for a 1/8th Å filter operating in the double bandpass mode, the peaks are at $\pm 1/16$ Å from the core of the line.

The double-bandpass mode:

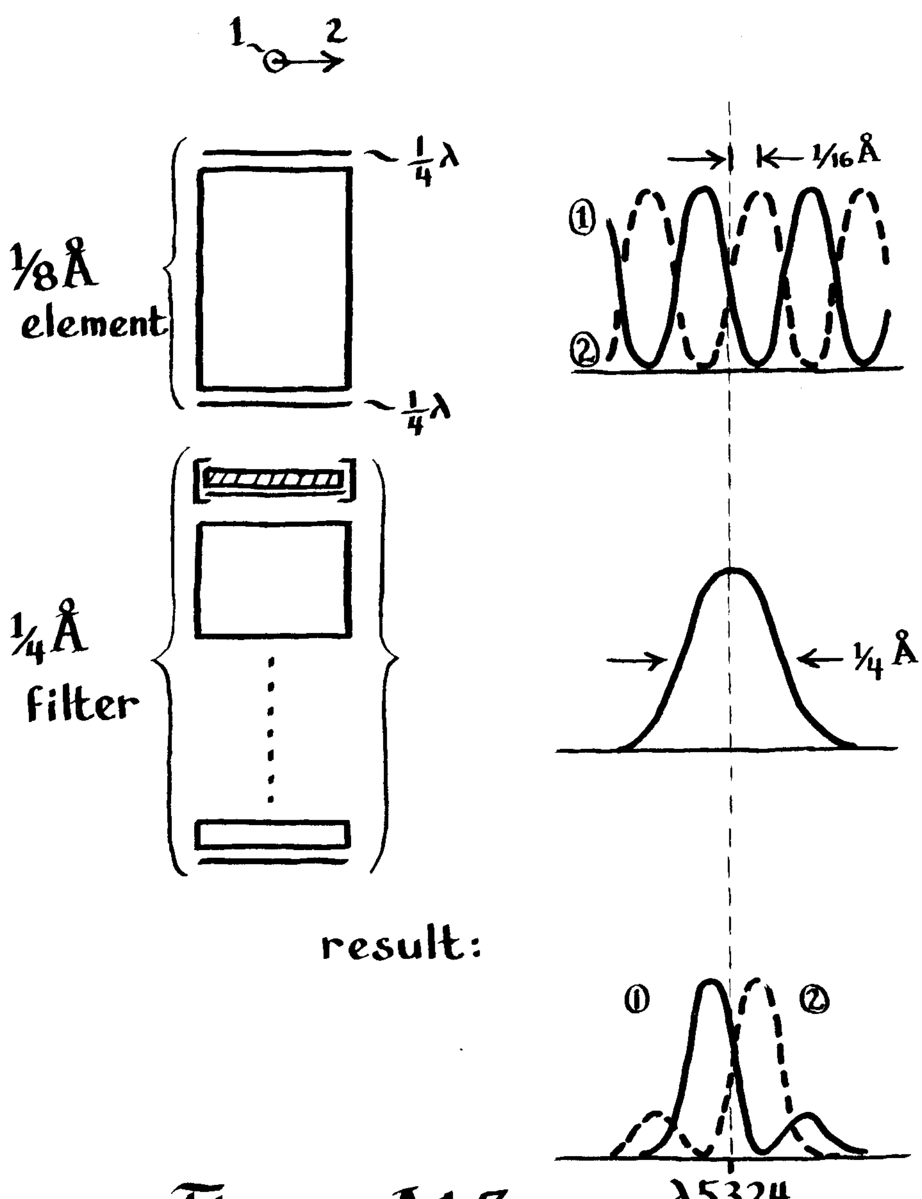


Figure A1-3.

minus quarter-wave plate. This is the mode of operation actually used with the videomagnetograph.

As described in Section III-B, a number of different birefringent filters were used during the first year of operation.

A. The Lockheed λ5324 Filter

The Lockheed λ5324 Filter is a converted Hallé filter, designed and assembled by Harry Ramsey at Lockheed Solar Observatory. With six main elements (partly calcite and partly quartz), it operates in a double-bandpass mode on the Fe I line at 5324 Å. The nominal bandpass (if the first element were tuned to maximize the central transmission) is about 1/7 Å. Major secondary transmission peaks occur roughly every 10 Å, and are blocked by a narrow-band interference pre-filter. Although the transmission was low (~1%), the spectral properties were "clean", and quite good performance could be obtained under favorable conditions; but since the filter is no longer available for use, an extended description is unwarranted.

B. The Spectra-Optics Filter

The Spectra-Optics λ5324 Filter is a new, all-calcite filter, designed and built expressly for use with the Caltech videomagnetograph. It has five main elements (1/8, 1/4, 1/2, 1, and 2 Å) plus a 1/4 Å "contrast" element (added just before the exit window and activated by means of an optional exit polaroid). Operating in double-bandpass mode, the 1/4 Å envelope is fixed on the 5324 Å Fe-line, while the 1/8 Å element is phased from wing to wing. The three thickest elements are "split" -- that is, they consist of calcite blocks which have been cut into two pieces and then re-cemented with a half-wave in between. The split configuration reduces the sensitivity of the filter to angles in the beam, but, at the same time, it reduces the flexibility of tuning, since wave plates chosen to work at 5324 would not, in all probability, work very well at 6103, or any other potentially useful wavelength.

Mechanically, the calcite blocks ride in a light, anodized aluminum tube, and are pressed together, at the ends, by rubber O-rings. Between the elements are the "tuning slugs" -- the combinations of polaroid and quarter-wave plate which act as circular polarizers. Each tuning slug shifts the transmission pattern of the preceding element. Two problems are encountered in tuning, however:

1. Unless the slugs are freshly greased, turning them will cause the cement to assume a fogged appearance, presumably from the accumulation and subsequent smearing of minute air bubbles. Usually, but not always, the condition is temporary, and disappears in a few days.

2. Even though the calcite blocks are locked by a keying-groove, a considerable amount of backlash and slippage is encountered. Hence the adjustment of the slugs is not entirely reproducible, and the procedure can become very frustrating.

Originally, it was intended that the slugs could be turned by means of gear shafts extending out the back of the filter, but due to certain changes in design, the original plan was never fully implemented. As a result, the system of tuning which now exists is rather unsatisfactory. Each tuning slug is mounted in a thin, knurled aluminum ring. By reaching a screwdriver in through one of the small "tuning ports" provided along the length of the cylinder, one can engage the teeth and thereby turn the slug, slightly (see Figure A1-4). The problem with this is that the filter has to be tuned at a uniform temperature close to the one at which it will operate ($\sim 40^\circ$ C.); but one cannot get at the tuning ports without completely removing the filter from its heating coil. Thus tuning the filter involves slipping the tube out of the heater, rapidly examining it on the spectrograph, making a change, slipping it back in, and then examining the result. Alternatively, one could attempt to tune the filter at room temperature, and then move the bandpass to the desired wavelength by heating, but this does not seem to work. Apparently the heater does not warm all the elements uniformly.

Figure A1-4: The Spectra-Optics filter

The Spectra-Optics filter consists of six calcite elements greased together and slid into an aluminum tube. The three largest are of a split configuration. Between the elements are tuning slugs (polaroid plus quarter-wave plate) sandwiched between glass plates. The filter is tuned by rotating the slugs, which may be reached by means of small access holes in the side of the aluminum tube. Only the last four tuning slugs need be adjusted, since the 1/8 Å element is tuned externally.

Note that the second thickest element is repeated at the end in an effort to improve "contrast" (Schoolman, 1973). It can be activated by replacing the normally clear exit window with a linear polaroid.

The Spectra-Optics filter

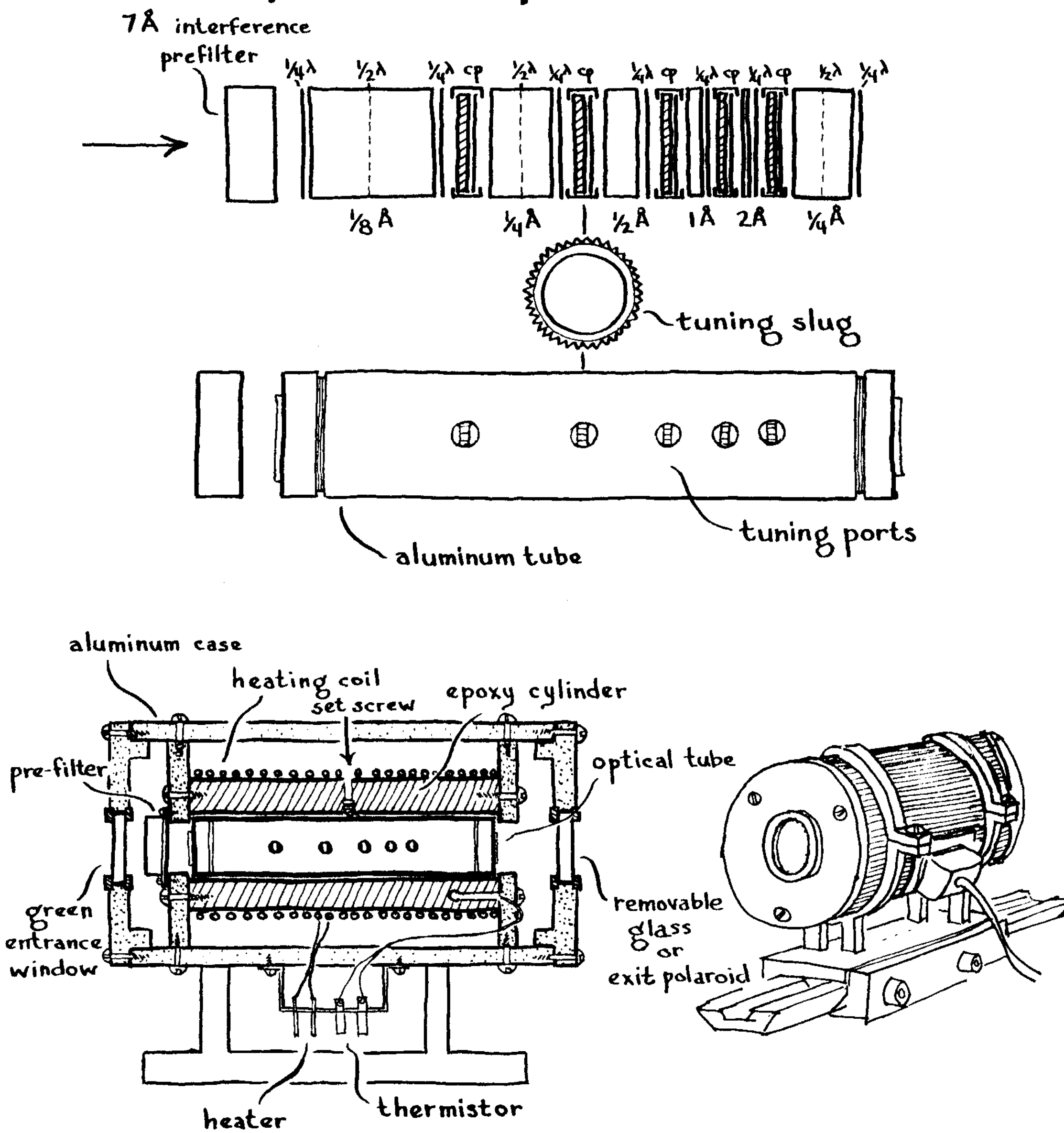


Figure A1-4.

Fortunately, the proper tuning, once achieved, is more-or-less permanent, and further modifications should not be necessary.

Incidentally, it is only the 1/4 Å part of the filter bandpass which is tuned during the procedure just described. The position of the first tuning slug is, at least in principle, irrelevant, since the proper phasing of the 1/8 Å element can always be restored by changing the orientation of the KDP; while the last, or "contrast", element, has no effect unless "activated" by an external polaroid. Since the contrast element is supposed to reduce the transmission in the sidebands (Schoolman, 1973a) it is possible to adjust the polaroid visually on the spectrograph (looking for a maximum transmission in the central peak). In practice, however, it is usually just as easy to wait and make the adjustment on the basis of the quality of the magnetograms: one tries running the system with the exit polaroid in various positions, and then, after examining the results, adopts whichever position seems to work best. Since the added element reduces the light level, it can be used only under favorable conditions. If no Doppler work is planned, a special glass-mounted polaroid can be substituted in place of the normal exit window.

Since the broadest element in the Spectra-Optics filter is a "2 Å" one, the main bandpass pattern repeats itself every 4 Å. The secondary peaks are rejected by a sharply-skirted

7 Å interference pre-filter centered on the 5324 line, and light very far to either the red or the blue is "trimmed" by colored glass. The front window of the filter is dark green, and a piece of yellow glass is inserted upstream, ahead of the second diagonal mirror. As long as the field stop is in place, the intensity of the beam is insufficient to cause any damage, except, perhaps, to an exposed, plastic polaroid placed ahead of the trimming.

The temperature of the filter is maintained by a single electronically-controlled heating coil. The filter has no built-in thermometer, but its temperature can be monitored by measuring the resistance of a thermistor embedded beneath the coil (the automatic controller operates on the basis of a second identical thermistor).

C. The Zeiss Filter

The Zeiss is a standard commercial H_α birefringent filter of high quality. The nominal bandpass is 1/4 Å. The difference between this bandwidth, and that of, say, the Spectra-Optics filter is due more to the longer operating wavelength than to any difference in the physical size of the elements; and in construction, the Zeiss is much more sophisticated. The elements, for example, are mounted in a specially geared rotating mechanism which allows the bandpass to be set anywhere in a 26 Å range ($\pm$13 Å from H_α). Normally the Zeiss is operated with the narrowest element pointed away from the sun. A mechanical handle is provided which permits the operator to flip out the last polaroid, changing the filter, in effect, from a 1/4 to a 1/2 Å bandpass.

For magnetic work, it is sufficient to tune the filter to one of the weak iron lines neighboring H_α (Beckers, 1968), but the signal obtained there is very weak. Far better results can be had by removing the pre-filter and looking for other bandpasses within the range of more favorable lines. In the case of the Big Bear Zeiss, a reasonably clean bandpass happened to lie within a few Angstroms of the popular Ca I line at 6103 Å; and by substituting a suitable pre-filter and adjusting the tuning wheel, magnetograms of quite high quality could be made in either wing of the line. Only the "1/4 Å" setting was useable, however, and because of the relatively low spectral sensitivity of the Plumbicon camera at longer wavelengths, the light level tended to be marginal.

The light level, and also the signal, can be considerably improved by turning the Zeiss into a double-bandpass filter; and that, essentially, involves nothing more than turning the filter over (so that what is normally the back end faces the sun) and flipping out the last polaroid (which is now the first). (In addition, the pre-filter, of course, has to be removed and placed in front of the main filter to prevent heat damage). The Zeiss 1/4-Å element does not seem

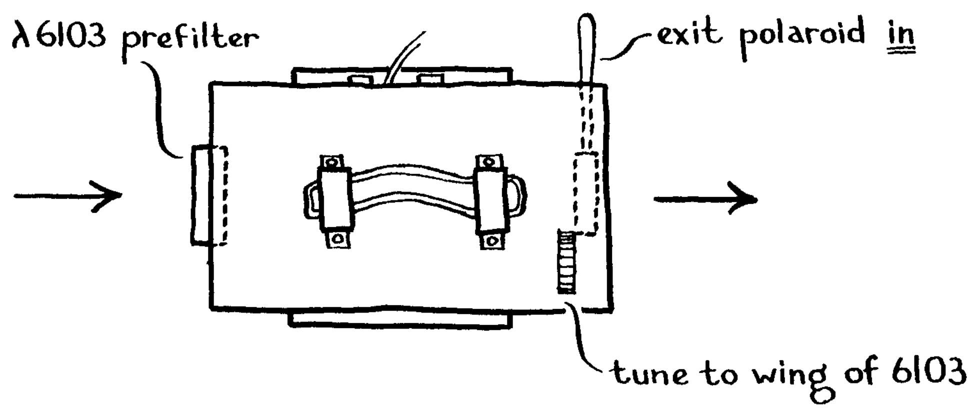
Figure A1-5: The Zeiss filter

Big Bear's 1/4 Å Zeiss H_α filter can easily be adapted for magnetic and/or Doppler work in the popular Ca I line at 6103 Å. To accomplish this, one need merely replace the normal H_α prefilter with one for λ6103, and tune the filter to line center. The Zeiss can then be operated as a single bandpass filter in either wing of the line. The light level is, however, somewhat marginal for the television camera. A double bandpass mode can be achieved by turning the filter over, so that the thickest element (which normally faces away from the sun) is in front. The "exit" polaroid can then be flipped out, and the first element tuned by means of the KDP. A mica wave plate taped over the front of the filter will be found useful in controlling the tuning of the first element, the orientation which adds and subtracts the ideal quarter-wave retardation to the calcite being determined by trial and error.

In both modes it will be necessary to insert heat absorbing glass in order to suppress the filter's broad infra-red leakage. It is also necessary to place an orange trimming filter in the beam ahead of the optics if one wishes to prevent damage to the prefilter.

The Zeiss filter

a. Single bandpass mode:



b. Double bandpass mode:

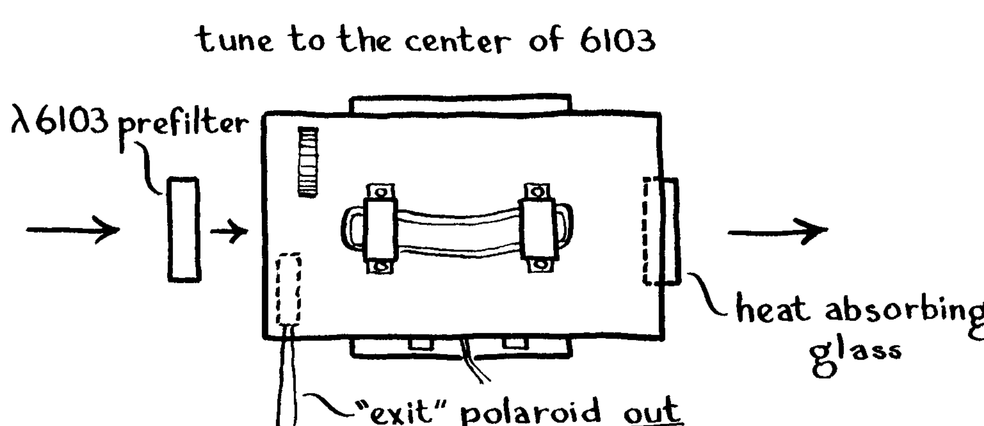


Figure A1-5.

to have the quarter-wave plate necessary for proper phasing in the double-bandpass mode, but that defect is easily rectified be taping a thin mica sheet over the entrance window. The filter is then tuned to the center of the line (as determined by the brightness of the image on the monitor), and the KDP adjusted to give the best magnetic "blinking". Some coordination between the orientations of the KDP and mica is necessary if the optimum effect is to be achieved. For a long-term project, or for more serious magnetic work, an internal re-tuning of the filter might be desireable. The bandpass at 6103 Å is nowhere near as clean as that at H_α (6563 Å).

When using the Zeiss one must also be aware of the possibility of infra-red leakage. A filter which performs well photographically can still let through enough infra-red energy to upset the Plumbicon and cause a washed-out, unfocussed-looking image. Whether or not this is a problem can be determined by adding pieces of heat-absorbing glass to the beam, and seeing if they have any effect.

APPENDIX II: IMAGE SCALE AND LIGHT LEVELS

The resolution of any video system is limited by the finite size of the beam used to scan the photosensitive target in the camera, a fact which is reflected in the construction of the picture out of a series of discrete horizontal lines. A .001″ diameter beam, for example, is incapable of extracting more than 500 lines of video information from the standard 12x16 mm target area (of a 1″ diameter faceplate). Higher resolution can be obtained, but (for a given light level) only at the expense of longer integration times, since in order to generate a picture, one must gather enough photons, within each resolution element, to accurately define the local intensity.

The videomagnetograph uses a camera of moderate sensitivity and resolution (Philips LDH 0151 camera chain with a Plumbicon type XQ1023R tube). This is a standard 30 cycle-525 line commercial system featuring high signal-to-noise and short memory time (that is, the picture can be changed rapidly and cleanly). 525 is only approximate, of course, the exact number of traces depending on just how the sweep circuitry is adjusted.

The spatial resolution of the system is also limited by what can be displayed on the monitor, but by then the dimensions are large enough that very little additional loss is encountered (although the display is normally adjusted to be somewhat larger than the screen, so that a few lines are lost at top and bottom). The principal loss encountered in connection with the monitor is its limited ability to portray the various shades of gray specified by the video signal -- particularly, the ability to register the same degree of brightness for equal signals occuring in different parts of the screen (an ability which requires a highly uniform coating of flourescent material on the face).

An ordinary television picture consists of some 400-500 interlaced dark and light lines. The content of the picture is conveyed both by variations in the intensity of the lines, and in their relative widths. As with the stripes on a zebra, the picture can be thought of either as being formed by a series of light stripes on a dark background or of dark stripes on a light background. Either way, at least one stripe is needed to represent even the smallest objects, and the number of stripes is only half the number of lines; that is, something like 200-250.

The resolution is, in fact, not even that good, since, unless the picture moves around, a feature affecting just a single stripe will tend to be disregarded as a random fluctuation either in the camera or in the monitor. Thus the actual vertical resolution of a "525 line" video system is more like 150-200 lines. The accuracy of this estimate can easily be verified by examining prints of various scenes displayed on the videomagnetograph monitor. If the height of the screen is adjusted to be about 15 cm, then essentially no features less than 1 mm tall can be identified with any certainty. The resolution in the horizontal direction (limited both by the physical size of the beam in the camera and by the frequency response of the video amplifiers) is essentially the same.

This sort of resolution is rather low for solar work. On a full-disk display, for example, where the entire $32'$ diameter of the sun is squeezed into the vertical direction, all features smaller than about $10''$ in diameter will be either lost or distorted. While this may be adequate for showing flares or sunspot groups, it is quite incapable of revealing any of the finer details, such as photospheric granulation or the filamentary fine-structure of the sunspot penumbrae, both of which have characteristic dimensions $\sim 1''$, and details still smaller. More importantly, it is incapable of displaying the fine-structure of the photospheric magnetic and velocity fields, both of which, according to the photographic cancellations, have details extending down to a similar scale -- details which one would hope to be able to explore with the videomagnetograph.

In order to display second-of-arc features, it is necessary to blow up the image at least by a factor of 10 (corresponding to a 3′x4′ field of view). Since the target area on the camera is about 12 mm tall, this means that the effective diameter of the solar image would have to be increased to about 12 cm. As indicated in Section II-i of the text, the incident light level at 5324 Å, after being corrected for the filter transmission, spectral bandpass, and line depth, is only about 0.05 μW/cm^2. The telescope, which takes all the light gathered within its 10″ (25.4 cm) entrance aperture and concentrates it into this 12 cm final image, increases the intensity by a factor of $(2.1)^2 \approx 4.5$, giving 0.2 μW/cm^2 on the camera faceplate.

At this light level (which is marginally adequate for driving the camera) the number of photons contributing to the production of a single frame is not large. If we are to suppose that the camera tries to subdivide the live image into 525x700 pieces, then we could equally well think of the target area as consisting of an array of some 370,000 tiny detectors, each with an area of $5\text{x}10^{-6}$ cm^2 (roughly, a square mil). Since 0.2 μW/cm^2 corresponds, in the green, to $5\text{x}10^{11}$ photons/cm^2-sec, one would expect each detector to collect about 10^5 photons in the 1/30 second used to generate a single live frame. Assuming a quantum efficiency of about 10%, this would result in the ejection of an average of 10^4 photoelectrons per resolution element per frame. The random statistical fluctuations ($\sim\pm100$) around this average would be sufficient to account for a ~1% noisiness in the video signal. Although higher light levels might seem desirable, relatively little could actually be gained, since a similar amount of noise is added again during the recording process (prior to cancellation).

The $3' \times 4'$ format is not necessarily ideal, however. In particular, it seems already to exceed the resolution limit imposed by the effects of seeing and telescope shake averaged over the inevitable 4-5 second integration time. Given this limited resolution ($\gtrsim 2''$), one would like to be able to display as much of the sun at one time as possible, and this calls for a somewhat smaller image. For magnetic work, the best performance has been obtained using a field of about $4' \times 6'$, a scale at which the resolution is limited more or less equally by seeing and by the scan lines. The light level (~0.3 $\mu W/cm^2$) is still marginal, but adequate, especially considering the fact that the sun (except near the limb) is an object of extremely uniform brightness.

In order to make Doppler cancellations it is necessary to insert an additional polaroid into the beam, and this generally lowers the light level to a point at which first-rate cancellations really cannot be made. In principle, the reduction in light level could be compensated for by making the image slightly smaller (a 50% reduction in size, for example, would double the intensity, and that would be just about right). Unfortunately, the alignment of the filter, especially in fast beams, is extremely critical, and to change the image size and alignment just for the sake of an occasional Doppler run would be most inconvenient. The last filter used with the magnetograph (the Spectra-Optics one) had significantly higher transmission than any of the previous filters and yielded a marked improvement in the quality of the Doppler cancellations. In general, the sensitivity of the Doppler cancellations is limited by factors other than simply the noisiness of the live pictures -- in particular, the background gradients due to non-uniformities in the filter bandpass force one to display the results with rather low contrast.

APPENDIX III: THE DATA DISC

As far as the magnetograph is concerned, the various parts of the Data Disc occupy about half of the space in the electronics rack. Physically, they consist of three separate units: the "Period Modems", the "Video Disc File", and the "Servo Control" (see Figure 11). The most important part, of course, is the disc itself. This is housed in the "File" chassis, so named because, in a sense, frames stored on the moving heads are placed like papers in a file. The disc is actually a highly-polished 16" diameter aluminum platter, with a tough ferromagnetic coating in which the pictures are recorded. It rotates at 1800 rpm (30 revolutions per second), so that a full video frame fits exactly into the amount of surface area covered on one rotation.

The recording heads consist of tiny ferrite chips, pressed against the underside of the platter by light bronze springs. The recording, of course, occurs only at a minute gap on the surface of the chip (with a roughly 4 MHz bandwidth, the physical space allotted to each picture element is not very large). Because of their delicate construction, the heads are vulnerable to mechanical failure. Indeed, this has proved to be one of the principal problems with the Disc. If a head cracks it can gouge the recording surface, and that in turn can set up bad vibrations causing still more extensive damage.

Figure A3-1 indicates the disposition of the heads. There is a total of six, counting the four video heads and the two clock track heads (all of very similar construction). Because the surface velocity decreases towards the center, the video heads are placed as far out as possible. For the fixed heads, this is within about 1/2" of the outer edge. The moving heads cover something like the outer third of the radius.

Underneath the disc, below the mounting board, is a series of matchbook-size circuit boards. Among other things, these cards contain the read-write amplifiers for the video heads. On occasion the cards stop working, either because of problems with the transistors, or because of a blown fuse (a tiny diode-like 1/8th A. fuse protects the recording coil from being subjected to continuous WRITE commands). When a failure occurs, the card, when asked to read or write a new frame, simply generates a moving noise pattern. A similar effect can, however, be caused by problems associated with the heads themselves. The exact source of the difficulty can usually be isolated by interchanging the cards (all of which are identical) between good and bad heads. In Data Disc terminology, incidentally, VM1, VM2, VF1, and VF2 refer to what we call Heads 1,2,3, and 4, respectively (VM, I assume, stands

Figure A3-1: The Data Disc

The positions of the two clock and four video heads is indicated in the upper part of the figure. The heads themselves are actually pressed against the underside of the disc, as shown below. The disc rotates at 1800 rpm, the speed being maintained constant by means of a servo-controlled motor which refers to the permanently-recorded "once-around" clock track. While most of the electronics is located in a separate "Period Modems" unit, the final read/write amplifiers will be found on a series of circuit boards under the disc. These cards should be checked when problems are encountered with the heads.

The Data Disc

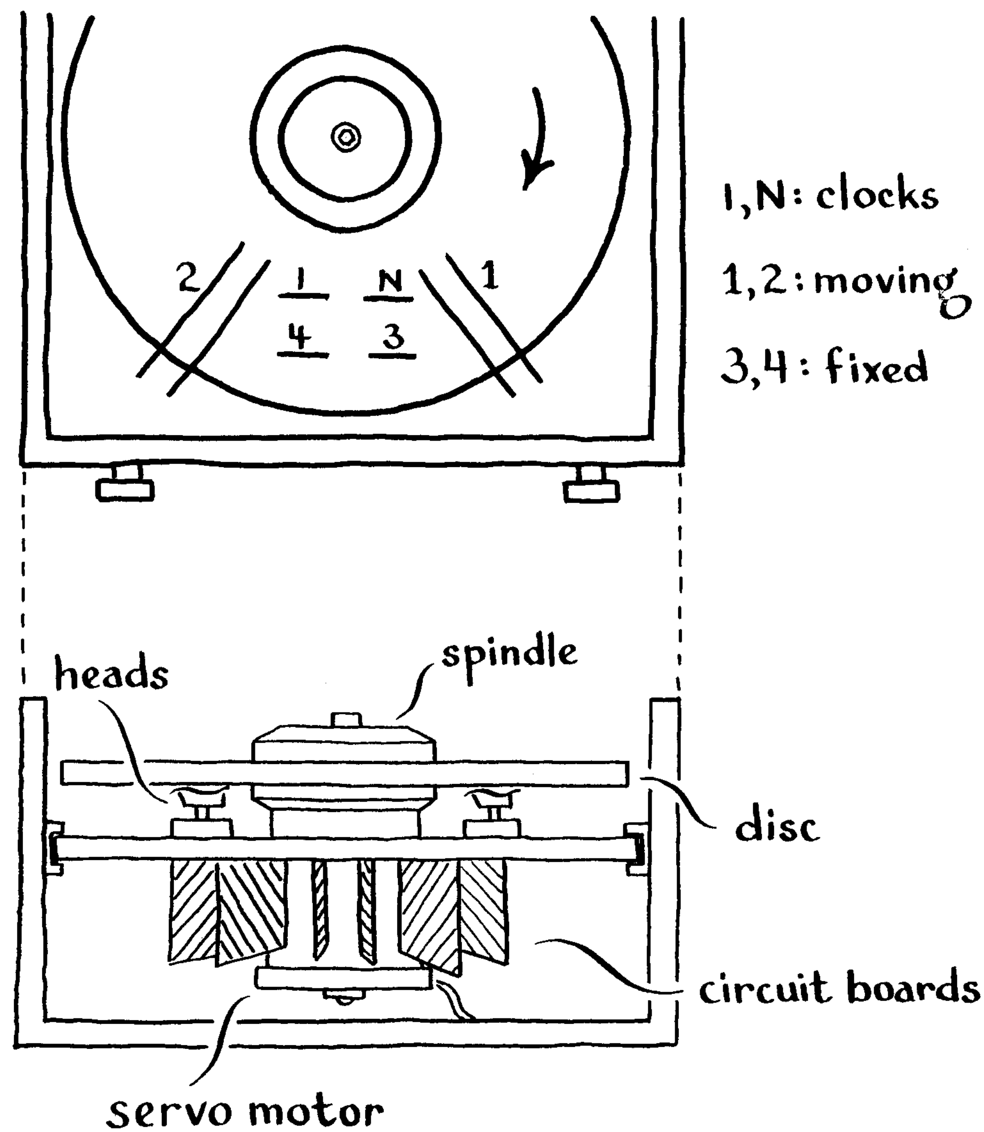


Figure A3-1.

for "video-moving", while VF stands for "video-fixed").

The clock tracks, as we have mentioned before, are used internally to keep the disc rotating at a proper speed. The circuits which in fact use them are located in the "Servo Control" chassis (which appears under the "Disc File" unit in Figure 11). Initially, the once-around track is used. Within about 30 seconds of turning on the power, the Disc locks onto it. An ammeter on the front panel indicates when this has been accomplished. Until the disc reaches the correct speed, a previously-recorded picture, if displayed, will appear torn on the monitor screen. Having locked in on the 30 Hz once-around, the Disc then uses the N-track to maintain precise line-by-line timing. In addition to their use in the Servo Control loop, the clock signals are also routed to the separate sync-interface buffer circuit which drives both camera and computer.

The third and final chassis in the Disc system is the "Period Modems" unit. As the name implies, this chassis contains the circuits for processing the video signals -- changing them from a normal analog form into the period-modulated version which can be recorded on the disc, and back. In addition, the "Period Modems" chassis contains gating circuits which route the modulated signals to and from the heads, as well as the actuator cards which supply power to the moving-head stepping motors. For reference, Figure A3-2 indicates the placement of the various circuit-boards in the period modems drawer. Note that there is only one modulator card and two demodulators. Additional power supplies are located in the servo control drawer and connected by cables.

As far as the connections between the Disc and the rest of the system are concerned, the most important are the connections for incoming and outgoing video signals. Since there is only one modulator card, there is only one video input. The resulting period-encoded signal can be routed by the modulator gate to any chosen combination of the four video heads. In practice, however, pictures are recorded on only one head at a time. The demodulator cards are shared by the heads in pairs. Thus there are just two output terminals, one for each card and not one for each head. By manipulating the cables beneath the disc the two outputs can be made to correspond to any desired combination of the four physical heads. Normally one output serves Heads 1 (moving) and 3 (fixed), while the other serves Heads 2 (moving) and 4 (fixed). Only one head can be played back at a time through each demodulator. In addition to the video inputs and outputs, there is also a multi-wire control cable through which TTL commands are issued for reading and writing frames and for stepping the moving heads.

Although the Data Disc is normally operated as a part of the larger magnetograph system, it can also be operated sepa-

Figure A3-2: The Period Modems Unit

The bulk of the Data Disc electronics is located on the circuit boards situated in the "Period Modems" drawer. The name is a reference to the fact that the video information is recorded on the disc in a period-modulated form, and that to be read back it must be demodulated. In addition to the modulators and demodulators, the unit includes the gate cards, which direct information to and from the individual heads, and the stepping cards, which control the movement of the moving heads.

The two step cards are identical, as are the two demodulators. If trouble is encountered, they can be interchanged.

The Period Modems Unit

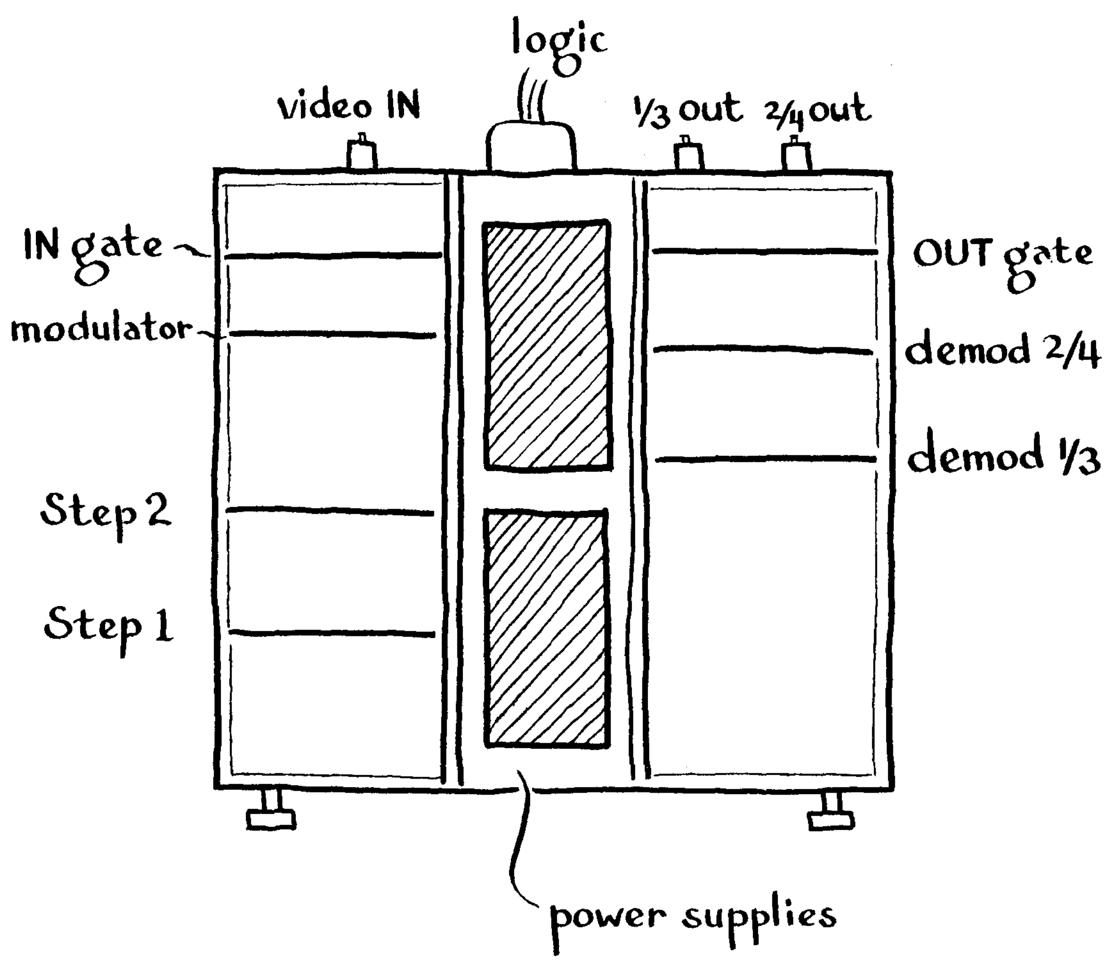


Figure A3-2.

rately, for trouble-shooting or for testing its performance. In this mode the live picture from the television camera is connected directly to the VIDEO IN terminal. The pictures recorded by the individual heads can then be examined by plugging a monitor into the appropriate output. Since the control circuitry described in Smithson (1972) no longer exists, the read and write commands have to be issued through the computer, using the teletype keyboard.

APPENDIX IV: PROCESSING TIMES

The time required for the video system to produce completed magnetograms is of interest for several reasons, the most important of which are these:

1. The spatial resolution of the final cancellations is limited by the effects of seeing and telescope shake averaged over the integration time. Because of this, it is desirable to keep this time as short as possible, consistent with the quality of cancellation which must be achieved.

2. The total time spent in recording and processing the pictures limits the maximum rate at which cancellations can be produced. In the study of such rapidly evolving phenomena as Doppler velocity signals, this limitation can be significant.

3. When the magnetograph is used in a time-sharing mode, the operator must know how long the diverting mirrors will have to be flipped in (or out) to provide light during the integration period.

A. The Recording Sequence

All of the timing in the magnetograph system is geared to the 30-cycle camera sweep, which, in turn, is tied to the Data Disc's permanently recorded once-around clock track. Although the computer may issue several commands at once, they are always timed to coincide with the receipt of a clock pulse, and hence are never issued at a rate of more than 30 per second. One might think, then, that the recording sequence for, say, a "64-frame average", in which 64 different live pictures are recorded on the Disc, would simply take $(64) \times (1/30) = 2.1$ seconds. In fact, it takes twice that long.

The problem, basically, is that the fixed heads are superior to the moving ones, and because of that, in recording the live pictures one would like to use the fixed heads exclusively. Since there are only two (namely, Heads 3 & 4), a maximum of two frames can be stored on them at any one time. If more than two are to be written, the initial two must be played back and transferred, for storage, to the moving heads. Since the only really critical function is the recording of the live pictures, even the slightly lesser quality of the moving heads is quite sufficient for storing and averaging these "raw" cancellations, but since no new live frame can be written during the transfer process, it does mean that one loses one potentially available frame for every pair that is recorded.

In addition, a second live frame is lost each time the KDP is switched. The problem here is that television cameras operate in a continuous "integrating" mode, each point on the faceplate collecting photons for the full interval that elapses between successive sweeps of the beam. Whenever the KDP is switched, it is sure to change the polarization of the light in the middle of the integration period for much of the target area. This unwanted "mixed" polarity signal can be removed only by rejecting everything that comes out of the camera for one full sweep (or frame) after each switching of the crystal.

These two effects together account for the loss of every other live frame, and hence, for the seemingly rather long integration times (see tables at the end of this section).

In view of the fact that one wants to accumulate frames as rapidly as possible, the loss of half the live pictures may seem rather wasteful. It is, however, unavoidable. The alternative would be to store a continuous series of live pictures of one polarity on one moving head, then switch the KDP and record a comparable sequence of the opposite polarity on the other moving head. Such a procedure gives inferior results both because the poorer quality of the recordings requires the use of more frames to achieve a given sensitivity, and because any systematic motion of the image in the interval between the recording of the two sequences will create prominent misregistration effects, particularly around sunspots.

While the resolution is actually no better when the rapid switching is used, it appears better. In the latter case, the individual cancellations are formed from closely-spaced image pairs, and, barring any extreme image motions, they will appear individually well-registered. Thus a gradual, systematic drift of the image over the integration period will lead to a sort of smearing and fuzziness in the final composite, and not to the sharp, contrasty bands encountered when long, continuous recording sequences are used. Rapid switching of the KDP does, however, require that many live frames be rejected.

In summary, the steps which constitute the normal recording sequence are the following:

1. A live, right-handed frame is recorded on Head 3.
2. The KDP is switched. The resulting mixed polarity frame is rejected.
3. A live, left-handed frame is recorded on Head 4.
4. The two recorded frames are played back simultaneously. The difference between them is formed by the multiplexer and recorded on one of the moving heads. The live frame in progress during the transfer is lost.

The loop can be repeated as many times as necessary. On the second time around, however, (since the KDP is switched only in Step 4) a left-handed frame will be recorded on Head 3 and a right-handed one on Head 4, opposite to what happened the first time. This may seem strange since it means that in order to maintain a uniform polarity in the cancellations the multiplexer will have to form the difference between the heads in an opposite sense on every other cycle. This apparent "problem" could easily have been avoided by switching the KDP a second time in Step 4 (when the live frame is going to be rejected anyway), but the alternation of polarities is actually intentional. By using the heads in different senses, the system tends to average out any systematic differences which may exist between them; and since their recording properties can never be perfectly matched, this is an important practical consideration.

The net effect of the recording sequence is to produce a series of "raw cancellations" -- each representing the difference between two live frames -- which wind up being recorded on a known series of tracks. For a 64-frame average, 32 such cancellations are formed, and they will be stored on the first 16 tracks of the two moving heads (half on each). It is the task of the computer, during the averaging routine, to recover these recorded pictures and combine them into one final composite.

B. Averaging Routine

The strategy employed in the averaging process is constrained by the fact that the multiplexer can add together at most two pictures at any one time. Thus in order to condense a large number of pictures into a few one has to play back the recorded pictures in pairs, making a new series out of the results. These "second-order" averages can then themselves be played back in pairs to form a third series, and so on, until all the pictures have been condensed into a single grand average.

A further constraint is imposed by the fact that small electronic delays are introduced each time a picture is played back and re-recorded on the Disc. On the monitor this causes the picture to slide a little to the right (by the width of about 4 or 5 television lines). In order to avoid misregistration in the final composite it is necessary to keep track of how many times each picture has been recorded, and to be careful to add together only pictures of the same "generation".

In addition, the fact that the Disc cannot read and write on the same head at the same time means that when the multiplexer forms the average, say, of two pictures recorded on the moving heads, the result, if it is to be recorded, must be written on one of the fixed heads, and vice versa.

Within the limits imposed by these constraints, it is important that the averaging be done as efficiently as possible. Not only will this save time, but it will also help to minimize the small, but significant, losses which are incurred each time a picture has to be re-recorded.

Like the recording sequence, the averaging routine also consists of a simple basic loop which can be repeated over and over. A portion of the routine used when both moving heads are operable is the following (this assumes that a series of raw cancellations has been stored on the moving heads and that they are to be added together):

1. The cancellations recorded on Head 1, Track 1 and Head 2, Track 1 are played back together and averaged. The result is recorded on Head 3 (fixed).
2. Heads 1 and 2 are stepped in one track.
3. The cancellations appearing on Head 1, Track 2 and Head 2, Track 2 are played back together and averaged, the result being recorded on Head 4 (fixed).
4. Heads 3 and 4 are played back, and themselves averaged. The result is stored on one of the moving heads (say, Head 1, Track 2).
5. The moving heads are stepped in and the cycle repeated.

As can be seen, the net effect of this routine is to reduce four cancellations into one. The decision to store the result on the moving head in Step 4 is quite natural, since the head is poised over the track anyway, and its contents, having already gone into the average, are no longer of interest. It is not necessary, however, to record the final picture on both moving heads. In fact, if one alternates, writing the intermediate averages first on one moving head, and then on the other, the same procedure (except that it becomes more complicated to specify where the relevant pictures will be found) can be used on a second (and third) pass through the data, each time reducing the total number of frames by a factor of four.

It should be noted that on each pass at least one of the moving heads has to step (at 30 steps per second) through the entire data set (most of which becomes irrelevant towards the end), since one of the current intermediate averages is always stored on the very last track. In practice, a roughly equal amount of processing time is spent in simply stepping the heads, as in actually transferring data. Schemes to reduce the amount of "leg-work" can be invented but they inevitably involve re-recording the cancellations even more times than is done at present, and are, therefore, quite undesirable. In principle, the processing time could be sharply reduced by using a video Disc with more heads and a multiplexer capable of averaging together more signals at one time. The interval between completed frames would still, however, be limited by the integration time, and, at least with the present television camera, that cannot be reduced. The present compromise, in which the processing time is about equal to the integration time, seems like a reasonable one.

When only one moving head is used (as is often the case due to mechanical failures), the processing procedure is actually simpler:

1. The picture on Track 1 is transferred to Head 3.
2. The head is stepped in one track.
3. The picture on Track 2 is transferred to Head 4.
4. Heads 3 and 4 are played back together, and averaged. The result is recorded on Track 2.
5. The head is stepped in another track and the process repeated.

On the second pass, every other track will have a useful frame; on the third pass every fourth track; and so on. As can be seen, the number of relevant frames is reduced by only a factor of two. This means that, for averaging together a given number of frames, considerably longer times will be required using one moving head than using two. Not only is the data set twice as long, but it must also be stepped through twice as many times. For the commonly used $N = 6$ and $N = 7$ modes (64- and 128-frame averages), the processing time is on the order of three times the integration time (i.e., about three times that encountered when using both heads).

C. Summary

Tables A4-1 and A4-2 summarize the time requirements of the videomagnetograph system:

Table A4-1: Time Requirements for Videomagnetograph System Using Two Moving Heads

N	Frames Used	Maximum Track #	Integration Time	Processing Time	Homes	Total
1	2	-	.13	-	-	.13
2	4	1	.27	.03	1	.33
3	8	2	.53	.13	1	.70
4	16	4	1.07	.63	2	1.71
5	32	8	2.13	1.37	2	3.73
6	64	16	4.27	3.53	3	8.55
7	128	32	8.53	7.20	3	17.28
8	256	64	17.07	16.83	4	38.10
9	512	128	34.13	33.83	4	76.43

Table A4-2: Time Requirements for Videomagnetograph System Using One Moving Head

N	Frames Used	Maximum Track #	Integration Time	Processing Time	Homes	Total
1	2	-	.13	-	-	.13
2	4	2	.27	.13	1	.42
3	8	4	.53	.43	2	1.06
4	16	8	1.07	1.33	3	2.75
5	32	16	2.13	3.43	4	6.56
6	64	32	4.27	8.20	5	15.05
7	128	64	8.53	18.80	6	33.63
8	256	128	17.07	42.30	7	74.19

The times are all in seconds. Because various schemes have been used for homing the moving heads, the averaging time has been split up into two parts: a "Processing Time", which represents the number of seconds actually occupied in stepping through the data and transferring pictures, and a second column giving the number of "Homes". (Since the moving heads are homed before each pass, the number of homes is exactly equal to the number of passes). To get the total time spent in averaging the pictures one has to add on to the "Processing Time" the amount of time required to execute the home commands. If the Disc's internal homing circuitry is used, the heads will move out at about twice the rate at which they step in, i.e., 60 tracks per second. Under these conditions, the total time spent in homing can be found simply by dividing the number of tracks over which the data are spread (given in the third column) by 60, and multiplying that by the number of home commands. At times, however, the system has been operated using an arbitrary fixed delay after the home command, in such a case the given times will have to be modified (see the troubleshooting section).

The "Total" time given in the last column represents the number of seconds elapsing from the beginning of the integration cycle to the moment at which the completed cancellation appears on the monitor screen. It does not include the time (about 2-3 seconds) which must be added at the beginning when a flip mirror is used (to allow the camera's automatic gain control to adjust to the light level), nor the time (again, about 2-3 seconds) spent at the end in photographing the monitor and examining the result.

APPENDIX V: THE COMPUTER PROGRAM

The computer program which operates the videomagnetograph is, with a few minor exceptions, the same as that originally written for it by Dr. Steve Schoolman. The program was written in PAL-11X assembler language, and exists both on cards and paper tape. The assembly language versions are useful both for troubleshooting and for producing new variants of the basic program; while the assembled and binary encoded versions, once punched on paper tape, may be loaded directly into the computer. The magnetograph uses the computer, basically, to turn on, at the right times and in the right sequence, a series of logical outputs, each of which is capable of triggering a specific operation in a specific piece of "peripheral" equipment (writing a frame on the Disc, for instance, or firing a camera).

A. Interfacing: Outputs

The computer is connected to the peripheral equipment by means of three 16-bit buffer registers, equivalent, electronically, to memory locations 177522, 177532, and 177542. Turning on a bit in any one of these registers generates a voltage which, in turn, activates an amplifier in a separate interface unit. The amplifiers boost the current levels to where they are sufficient to drive the external devices without loading down the computer.

Three rows of wheat-grain lights, corresponding to the 48 outputs, appear on the front of the interface chassis (Figure A5-1). The lights are activated by a parallel set of amplifiers, and function solely to inform the operator that the particular line is "on". As can be seen from the figure, not all of the available bits have been assigned functions. Indeed, even some of the labelled ones (the ones in parentheses) are just "echoes"; that is, dummy lights which the computer can turn on to indicate that a particular task has been performed, but which themselves play no role in the actual performance of the task. The echoes are used in connection with the functions that would otherwise be triggered by pulses too short to turn on their own lights.

The WRITE function, for example, by which pictures are recorded on the Disc, cannot be left on for more than a few seconds without damaging the amplifiers. To avoid doing that, even in the manual mode, the computer is programmed so as to turn on the WRITE outputs just for the single 1/30 sec needed to record a frame. Having done this, the WRITE output is turned off and a second light (the echo light) turned on. since the second light does not activate the Disc, it can be left on indefinitely without danger. Some of the other functions, such as the head steppings, are triggered by the ends of pulses, and so for them too it is convenient to have an

Figure A5-1: The computer interface

The three rows of "wheat-grain" lights correspond, as indicated, to the bits of the three output words which can be controlled by the computer. With the exception of the light labelled "spar ready", the functions are as indicated, while the "spar ready" is simply an otherwise unused light which happens to serve as an indication of when the telescope is available for use. In the computer memory, the outputs have been assigned locations 177522, 177532, and 177542, respectively.

In addition to the 48 control lights, the interface unit is also the home of the two "nixie" tubes, which read out the location of the moving heads, and of six BNC connectors, by means of which one may monitor the various input voltages which the computer recognizes during its interrupt sequences. Because of the narrow portion of the disc surface actually used in recording pictures, the tracks used by the two moving heads do not overlap, and the numbers are entirely independent of each other.

E = Erase   I = In   X = Multiplexer   K = KDP+
W = Write   O = Out   M = Mirror   S = KDP−
R = Read   H = Home

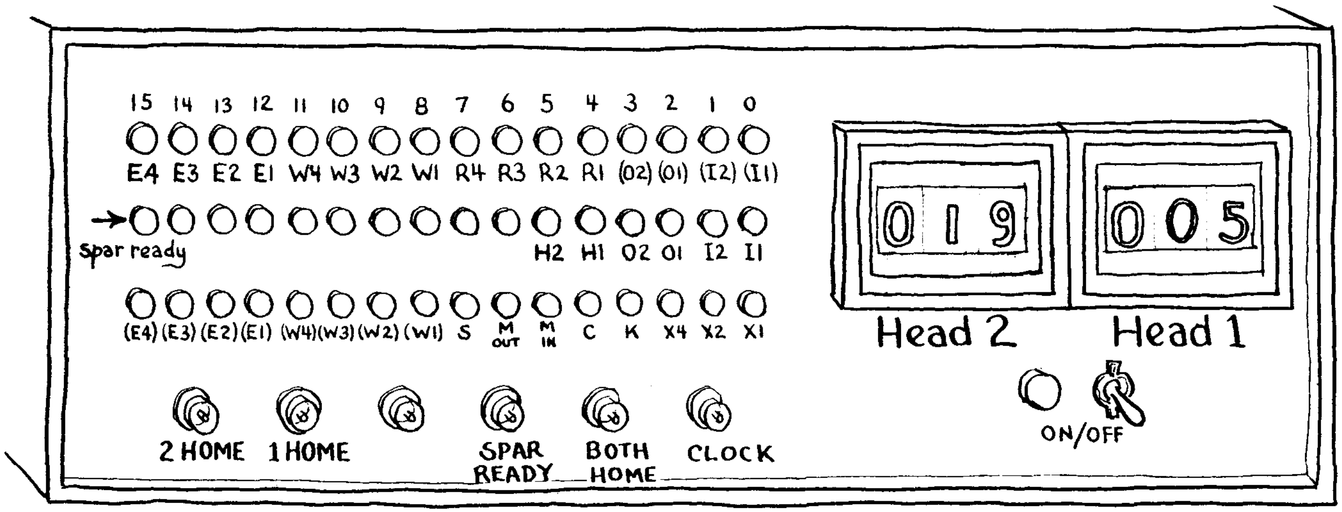


Figure A5-1.

"echo" to indicate that the operation has occurred. The echo system is used exclusively in the "manual controller" portion of the program.

B. Interfacing: Inputs

In contrast to the 48 outputs, the computer requires relatively few inputs in order to operate the magnetograph. Of these, by far the most important is the 60-cycle clock signal which is generated by the sync-interface unit from the Data Disc once-around. As has been mentioned elsewhere, most of the system timing hinges on this clock. The clock is a necessary reference without which the recorded pictures could not be played back, subtracted and averaged together in correct geometric register.

The program accomplishes its synchronization to the once-around clock by using "interrupt" routines. In this mode, a WAIT instruction is inserted into the program. Upon encountering the WAIT step, the computer will pause, doing nothing further until a clock pulse is received on the "Interrupt" line. On receipt of the signal, it goes through a "trap handler", and then returns to continue the program. The trap handler tells the computer to transfer the contents of processor registers RØ, R1, and R2 into the three output buffers. If these registers have been primed up with the data which one wants to transmit, then the interrupt routine will hold the data, lighting up the outputs at the exact moment the clock pulse is received.

In order to write just one frame per 1/30 sec, the computer has to "divide" the 60-cycle clock by using the WAIT steps in pairs. The data can be transferred on the first, while the second (which kills the spare 1/60 sec) can be used to clear the output lines. If the computer loses a pulse, the interlaced fields will get mixed up in such a way that, on the monitor, the vertical blanking bar (which normally appears at the sides just off-screen) will show up running down the middle of the picture. Slipping a second 1/60 sec will restore the proper registration.

Even steps which do not need to be precisely synchronized to the camera sweep or disc rotation (such as mirror flipping and head stepping) are generally activated by the same double WAIT routine as a matter of convenience. Thus even the exposure times for the film camera used to photograph the monitor are measured in 30ths of seconds.

In addition to the clock, the computer responds to two other inputs from the outside world. One of these is the SPAR READY signal, which tells the program when it is safe to flip the mirror into the beam and start the integration sequence, if the telescope is being shared with other cameras. The other is the HOMED signal from the moving heads. Actually there are three HOMED signals: one for each of the heads separately, and one for the two of them together. The reason for the HOMED signals is that the time it takes for the heads to move out to their starting positions depends on how far in they happen to be when the HOME command is given. Rather than having to wait always for the longest possible time, the Disc is equipped with photoelectric sensors which generate control signals whenever the heads reach either their extreme in or out positions (this signal is also required internally by the Disc itself to keep the stepping motors from running up against the stops). The moment the HOMED signal is received, the computer can proceed. Even during the homing routine, however, it has to keep track of the 60-cycle pulses so as not to lose count.

The five input lines can be examined by means of the BNC connectors on the front of the interface chassis (see Figure A5-1).

C. Listing Format

Figure A5-2 shows a sample page from the assembler printout (in this case generated by the PDP-10 at Caltech). The instruction sequence is listed in the central column. Comments appear to the right. On the left are the addresses into which the instructions are placed, followed by their machine language encoded forms. All of the numbers are octal. Even the number 2000 in the "MOV #2000, RØ" is a 2000_8, and

Figure A5-2: The program

The figure shows a small portion of the program used to control the system sequencing. In this computer-assembled printout, the instructions appear in the central column, with their coded versions to the left, and comments to the right. The portion shown happens to represent the start of the recording sequence. The actual acquisition of data begins with the steps labelled RCDSEQ, and the comments give some idea of their function.

In essence, the system is primed by loading the desired output into registers RØ, R1, and R2 of the central processor, where it remains until being transferred to the output buffers, upon receipt of clock pulse, during the WAIT routine. Note that a pattern of double WAIT instructions must be used to maintain the proper 30-cycle timing.

The THROWAWAY frame referred to at the top of the page is something used at the start of the recording sequence to clear the fixed heads of any data which might previously have been recorded upon them. It is thought to improve the signal-to-noise slightly.

```
PALX11  VØØ3    15-FEB-73       17:33   PAGE 6

                                                                        ;PAGE 6

ØØ1536  Ø127ØØ  ØØ2ØØØ          THROW:  MOV #2ØØØ,RØ            ;W3 THROWAWAY FRAME
ØØ1542  Ø16767  ØØ6642  17634Ø          MOV CLTRAP,TRAPØA
ØØ155Ø  Ø12767  ØØ1566  ØØ6646          MOV #IRA1,INTRTN        ;KB INT RETURN ADDR
ØØ1556  ØØ5Ø67  176214                  CLR PS                  ;PRIORITY Ø
ØØ1562  ØØØØØ1                          WAIT
ØØ1564  ØØØØØ1                          WAIT
ØØ1566  Ø127ØØ  ØØ4ØØØ          IRA1:   MOV #4ØØØ,RØ            ;W4 THROWAWAY FRAME
ØØ1572  Ø12767  ØØ16Ø4  ØØ6624          MOV #RCDSEQ,INTRTN      ;KB INT RETURN ADDR
ØØ16ØØ  ØØØØØ1                          WAIT
ØØ16Ø2  ØØØØØ1                          WAIT

ØØ16Ø4  Ø12767  ØØØ2ØØ  176164  RCDSEQ: MOV #2ØØ,PS             ;PRIORITY 4
ØØ1612  Ø127ØØ  ØØ2ØØØ                  MOV #2ØØØ,RØ            ;W3
ØØ1616  1167Ø2  ØØ6612                  MOVB KDPSET,R2          ;KDP POLARITY
ØØ1622  Ø12767  ØØ164Ø  ØØ6574          MOV #IRA2,INTRTN        ;KB INT RETURN ADDR
ØØ163Ø  ØØ5Ø67  176142                  CLR PS                  ;PRIORITY Ø
ØØ1634  ØØØØØ1                          WAIT
ØØ1636  ØØØØØ1                          WAIT

ØØ164Ø  Ø12767  ØØØ2ØØ  17613Ø  IRA2:   MOV #2ØØ,PS             ;PRIORITY 4
ØØ1646  ØØØ367  ØØ6562                  SWAB KDPSET             ;CHANGE KDP POLARITY
ØØ1652  1567Ø1  ØØ66Ø6                  BISB STEPIN,R1          ;1 OR 2
ØØ1656  1167Ø2  ØØ6552                  MOVB KDPSET,R2          ;KDP POLARITY
ØØ1662  Ø12767  ØØ17ØØ  ØØ6534          MOV #IRA3,INTRTN        ;KB INT RETURN ADDR
ØØ167Ø  ØØ5Ø67  1761Ø2                  CLR PS                  ;PRIORITY Ø
ØØ1674  ØØØØØ1                          WAIT
ØØ1676  ØØØØØ1                          WAIT

ØØ17ØØ  Ø12767  ØØØ2ØØ  176Ø7Ø  IRA3:   MOV #2ØØ,PS             ;PRIORITY 4
ØØ17Ø6  Ø127ØØ  ØØ4ØØØ                  MOV #4ØØØ,RØ            ;W4
ØØ1712  1167Ø2  ØØ6516                  MOVB KDPSET,R2          ;KDP POLARITY
ØØ1716  Ø12767  ØØ1734  ØØ65ØØ          MOV #IRA4,INTRTN        ;KB INT RETURN ADDR
ØØ1724  ØØ5Ø67  176Ø46                  CLR PS                  ;PRIORITY Ø
ØØ173Ø  ØØØØØ1                          WAIT
ØØ1732  ØØØØØ1                          WAIT
```

Figure A5-2.

not a 2000_{10} as might have been suspected. This is an instruction to write a frame on head three, as the comment indicates, because when expanded into a 16-bit binary number the 2000 becomes a 0000000010000000; and this number, loaded into the first output buffer, will turn on the W3 line (the eighth light from the right in the first row).

The reason that there are three columns of numbers after the addresses is that in PDP-11 machine language more than one word is often required to represent the content of a single instruction. At least one is required just to specify the operation; while a second and third may be required to specify what numbers or locations are to be operated upon. The address given in the left-hand column refers to the first word only. The subsequent words, when present, are placed in successive locations, the exact addresses of which must be determined by deduction.

Since the numbering system is by bytes (8-bit units), the addresses advance by twos. Thus the first line of the listing shown in Figure A5-2, for example, indicates that in order to properly encode the MOVE instruction, the number 012700 must be placed in memory location 001536. 012700 is one of the codes indicating a MOVE operation. The fact that in this particular case a number is to be moved into one of the processor registers is implicit in the form of the instruction, but the number has to be specified separately.

The listing does not state explicitly, but by deduction one can figure out that the 2000 must go in location 001538, the next location in core. Of course, the 8 is illegal in octal, so the proper way to write the address is 001540. The next instruction should begin in location 001542, and as can be seen, this is indeed the case.

D. Layout of Program

The program is divided, overall, into three main parts. The first of these is the "initial dialog" section, in which the computer extracts from the operator the working parameters for the day, such as the number of frames to be averaged, the polarity convention to be observed, etc. These data, entered from the teletype keyboard, are automatically stored by the program. In principle, the same data could be entered directly into core using the toggle switches on the computer, but that would be considerably more laborious. In all versions of the program, the initial dialog instructions start at location 440.

The second, or "automatic controller" section, contains the instruction sequence actually used in producing the Doppler and magnetic cancellations. The precise sequence is, of course, partially determined by the parameters chosen during the initial dialog. This section begins at a location called STARTA, the exact address of which varies from version to version, but can always be determined by looking in the assembler printout. If one wishes to avoid the initial dialogue sequence (and keep the parameters used the day before), the program can be started directly at STARTA by toggling in the correct address. To simplify this procedure it is customary to put in location Ø an instruction to JUMP to STARTA. Thus starting the program at Ø is equivalent to starting it at STARTA.

The last main section of the program is the "manual controller", which permits one to manually excite the various bits in the output buffers by issuing commands on the teletype keyboard. This facility is particularly important because most of the peripheral devices (other than the camera and the monitor) lack their own control circuits, and can, therefore, be activated only through the computer. In particular, the computer has to be used to ask the Disc to record and playback frames, or to step its moving heads. As with the other parts of the program, the manual controller can be started directly at MAN.C by toggling in the proper address, if one wishes to bypass the other sections.

In addition to the three main sections, many of the more commonly used instruction sequences, such as decimal to binary conversions and count-downs for generating controlled delays, are collected as a series of subroutines at the end of the program. The complete magnetograph program occupies between half and two-thirds of the available space in core. The rest is blank.

Of the three sections, only the initial dialogue will run without the Disc. The other two require the clock track for timing, and, if it is not present, will hang up on the WAIT steps. If one must test or debug the program when the Disc is not running, it is necessary to use a dummy clock.

E. Program Errors and Their Correction

Most of the problems encountered in connection with the computer are caused by accidentally starting the program at an incorrect address, either by toggling in the wrong one, or by hitting the wrong sequence of switches when returning from a manual HALT.

As we have seen, not all the words stored in the memory are instructions -- some of them are simply numbers or the addresses of numbers which are to be operated upon. Wherever the program is started, however, even if incorrect, the computer will attempt to interpret the data it finds in the first location as an instruction. Such incorrect interpretations could well direct the computer to modify the contents of some other location in the memory, and thereby permanently damage the program. Thus if, for example, one were trying to start the program at the top of the section shown in Figure A4-2, that is, at location 1536, but had accidentally toggled in a 1540 instead, the computer would find the number 2000 in the starting address. Interpreted as an instruction, the code 002000 tells the computer to BRANCH, which is not at all what was intended.

As a rule, most false starts tend to run only a short way before halting on an illegal "command", and, therefore, cause only limited damage to the program. While the errors can always be corrected by reloading the program, the paper tape reader is slow and not entirely reliable. Frequently more than one try is needed to load the tape correctly, and with most versions of the program a number of manual corrections have to be added anyway. Thus when the damage is small, it is often more efficient to locate and repair the errors by hand.

In order to be able to correct errors it is not necessary to understand exactly how the program works. The comments appearing in the listing give a pretty fair idea of what is supposed to be going on, so if one can figure out where the problem might be, it is just a matter of comparing the contents of the memory with the numbers that appear on the listing. If the Disc starts to hang up in the HOMING sequence, for example, the problem is probably in the HOME routine. The particular section of the program that deals with this function can be found by looking at the list of symbols collected at the end of the assembly printout (see

Figure A5-3). The problem can also be in a subroutine referred to by the affected section. Usually the faulty word can be found within a few minutes. If not, one should consider reloading the program.

F. Program Modifications

Understanding the assembly listing is also important if one wants to be able to make minor modifications in the program without having to generate a completely new version, and the ability to do so is quite valuable. The delays and exposure times used in photographing the monitor, for example, are determined by "counting down" numbers stored at certain locations in the memory. The delays can, therefore, be modified simply by altering the contents of those addresses, if one knows where they are. It is also possible to change the meaning of the instructions which activate the output buffers by altering the words that will be transferred into them. In such a way one can, for example, arrange things so that the live frames will be averaged together instead of being subtracted.

For troubleshooting, it is even useful to insert JUMP instructions, causing the program to skip over or repeat certain sections. When setting up the magnetograph with a new filter or KDP, for example, it is customary to place an instruction at the start of the averaging sequence telling the

Figure A5-3: The listing

The glossary appearing at the end of the computer-assembled printout is simply a list indicating the address in memory to which each labelled step in the program has been assigned. Note, for example, the addresses of steps IRA1, IRA2, and IRA3, all of which appear in Figure A5-2.

This listing is extremely useful in debugging the program since it allows one to easily determine the location of most possible problem areas.

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ABRIF	002200	FIND2	003072	LF	000212
ACCEPT	003166	FINIS	006430	LOLIM	010436
AMIGO	004764	FLIP	001372	LOMSG	010264
ATOBCD	010010	FLIP1	001402	M,A	006526
AUTO.C	002572	FLOP	002042	M,ALT	005632
AVGSEQ	002244	FLUTE	003260	M,CLR	006674
BOAT	010406	FRIEND	005000	M,ERAS	005156
BONE	002724	GOHOME	007230	M,EX	005212
BRIAN	002472	GOMAN	004666	M,FLIP	006726
BTEST	007032	GOSTEP	004542	M,GOT	006036
CAM2	003174	GRAB	004002	M,GOTO	006000
CAMSET	001162	GUITAR	003730	M,H	005360
CFOUND	007064	H1OR2	010422	M,H1	005372
CHAR	007714	HMAN	004320	M,HDUN	005376
CHOICE	004040	HOME	007140	M,HOME	005322
CLEAR	007574	HOME1	007162	M,I	005430
CLTRAP	010410	HOME2	007206	M,IN	005422
CMODE	010412	HOMED	007320	M,IN1	005506
CMSG	010116	HORN	002764	M,INX	005472
COMAND	010344	I0BUF	177522	M,IO	005512
CONTR	000640	I0STAT	177520	M,IODO	005532
CR	000215	I1BUF	177532	M,IOX	005476
CRLF	010370	I1OR2	010430	M,IR	005760
CRSTAR	010374	I1STAT	177530	M,KB	005660
CTROL	010202	I2BUF	177542	M,MANY	005646
DATAIN	007624	I2STAT	177540	M,MOVE	007072
DELAY	007504	IF012	007336	M,MPXR	005270
DING	010400	IMSG	010146	M,NSTP	005656
DO,C	003342	INIT	001454	M,O	005610
DO,CR	003454	INPUT	007654	M,OUT	005416
DO,E	003350	INTRTN	010424	M,OUTX	005624
DO,I	003356	INTRVL	010426	M,OW	005754
DO,J	003364	INTSET	001070	M,PLAY	006232
DO,K	003374	IO	010402	M,READ	005106
DO,N	003402	IRA1	001566	M,RITE	006514
DO,O	003410	IRA10	002340	M,RPT	005572
DO,ONE	004636	IRA11	002416	M,RSET	005144
DO,P	003466	IRA2	001640	M,RW	006456
DO,RTN	003526	IRA3	001700	M,RX	005130

Figure A5-3.

computer to JUMP back to the start of the recording sequence. This modification puts the program in a mode where the KDP is continuously modulated. On the "live" monitor (direct from the camera) one sees (hopefully) the blinking characteristic of Doppler or magnetic signal, while on the magnetograph monitor one sees the first order cancellations. At the same time, the computer keeps track of the SPAR READY pulses, so that the magnetograph will not interfere with other cameras sharing the same beam.

In order to make major modifications it is necessary to have a fairly good understanding of the PDP-11 machine language. The programmers' handbooks kept at Big Bear will, no doubt, prove useful in this respect.

APPENDIX VI: COMMON OPERATING PROBLEMS AND TROUBLESHOOTING

Although the magnetograph is continually developing new and unforseen maladies, there are a number of well-established ones whose symptoms may be easily recognized. The following list indicates some of the most important of these, both for the benefit of those who may wish to use the system in the future, and for the benefit of those who may wish to use the existing data, for many of the frames on the films are marred by such defects, and, once recognized, should be disregarded in any serious analysis.

1. Push-Pull

Symptom:

The monitor screen is completely covered by a fine-grained pattern of moving noise or "snow". This noise is generated by "ringing" in the modulator circuitry in the Data Disc. When present, it is introduced into every frame as it is being recorded. Attempts to write frames on the Disc manually will result only in noise.

Cure:

The problem was finally tracked down to a faulty connector on the modulator circuit card, which has since been repaired (1974). The problem will, however, be seen at times on most of the existing movies. In addition, a virtually identical symptom has, in the past, been caused by straining the multi-wire cables connecting the various Disc components in the rear. It is alleviated by sliding the drawers in and out until a good contact is made (usually with the top one staying about halfway out).

2. Clock Track

Symptom:

Electronic glitches developed in the high-frequency clock track will cause the video sync signals to become unstable or erratic. The live picture tends to develop a "rip", and the processed cancellation will be divided into 2 or 4 unregistered quadrants separated by misplaced horizontal and vertical blanking bars. Examination of the clock track signal on the oscilliscope will generally reveal some kind of artifact superimposed on the normally "clean" square wave, although it may be quite difficult to see.

Cure:

The problem is easily corrected by writing a new clock track (which simply involves recording one frame's worth of the live sync signal from the Plumbicon controller onto the Disc). A transistor amplifier is permanently mounted between the controller and the Disc for this purpose. Be sure to activate it with a fresh $4\frac{1}{2}$V battery before attempting to write the new track. Record the track while the live image is being synced off the disc. Several attempts may be necessary, since the "write" button has to be pushed roughly in phase with the permanently recorded "once-around" clock. The success or failure of each effort will be immediately obvious from the quality of the live image on the monitor (i.e., is it still torn or not?).

Recording new clock tracks is easy. Whenever the system develops any new, peculiar or erratic behavior, whether or not it displays the classic symptom of the torn picture, it is a good idea to try this. It may solve the problem.

Erratic fluctuations in video gain, for instance, which caused improper cancellations for a considerable period of time, disappeared as soon as a new clock track was recorded. Erratic behavior of the computer program is also sometimes improved.

3. Branch to 0

Symptom:

This is a computer problem causing the program to abort at unpredictable times during the course of its operation and start over at location 0 in the memory. While this does not lead to the production of any defective frames, it does lead to gaps in the data, and to uneven frame rates on the movies.

Cure:

No really effective cure for this problem has yet been found, although at times its occurence is quite infrequent. Placing an instruction to restart the program in location 0 prevents the operation of the magnetograph from coming to a halt at this point, but, it does not replace the lost data. Efforts to insert an instruction causing the program to branch back to where it aborted from proved unsuccessful.

4. Computer Hangup

Symptom:

When the computer is asked to remain in a WAIT condition for any substantial length of time (i.e., waiting for an external input to trigger a continuation in the program), there is a finite chance that it will simply cease to run. At times, this will happen whenever the computer is asked to wait for more than 2 or 3 seconds, while at others it can "wait" for an hour or more with no problem (although that is rare, in my experience).

Cure:

When the computer RUN light goes out, the only way to get the program going again is to manually restart it. Many of the longer gaps in the movie sequences, when not caused by clouds or other problems, were due to such computer hangups occuring when the operator was not immediately on hand.

Efforts to re-write the portions of the program in which the WAIT routines occur, or to use different versions of the program, have proved to be of no avail, nor has consultation with the computer repair people proved to be at all enlightening on this or the "branch to 0" problem.

5. Saturation in Live Picture

Symptom:

When the live picture is saturated, the highlights assume a featureless white appearance. Reference to the oscilliscope trace will indicate a "clipped" white-level. On the cancellations, these areas will correspond to regions of featureless flat gray.

Cure:

The saturation can occur either in the camera itself or in the subsequent electronics.

Saturation in the camera is caused by insufficient BEAM current for the prevailing light level, so that the photocathode is not completely discharged between frames. Provided the light level is not too high, the problem can be solved by advancing the BEAM control. The proper setting is the one at which the effects of saturation first disappear.

Saturation arising during the subsequent amplification of the video signal can always be cured by manually decreasing the gain. The disadvantage of the MANUAL mode is that one must continually readjust the gain throughout the day if optimum results are to be obtained.

It should be possible to obtain unsaturated pictures using the automatic gain control circuitry, and thus avoid this complication. The AGC circuit can be operated in either of two modes: AVERAGE and PEAK-to-PEAK.

In the AVERAGE mode, the average video level is adjusted to an intermediate level between 0 and 1 Volt. If the scene contains any high-contrast highlight spikes, these will be clipped. This is particularly troublesome when the region being observed is on the limb --- in which case the entire solar disk will tend to be a saturated white. The AVERAGE mode is, therefore, not often used in connection with the magnetograph.

The PEAK-to-PEAK mode is supposed to adjust the gain so that the brightest feature in the scene is just barely clipped. When properly operating, this is what is normally used.

Whatever mode is used, it is always true that the best magnetograms are obtained when the video signal is as large as possible, short of saturation.

6. <u>Saturation of the Magnetic (or Doppler) Signal</u>

Symptom:

If the operator looks at the oscilliscope when the final cancellation is being displayed on the television monitor, he will notice that the most prominent magnetic features are represented by sharp spikes sticking out above and below the average video level. Just like the features in the live picture, these will be clipped flat at top and bottom if too large.

Cure:

Saturation in the magnetograms can be reduced or eliminated by adjusting the "N-knob" on the multiplexer. This modifies the gain used in "averaging" pairs of frames during the processing routine. The optimum setting is that for which the fields just barely saturate on the final frame. Either higher or lower settings will result in poorer signal-to-noise.

7. Weak Signals

Symptom:

A general weakness, or noisiness, of signal is certainly the most common complaint, and also the most difficult to remedy, since it can be caused by any one of a large number of problems, or by a combination of small contributions from many of them. Weak cancellations will result either if the signal is weak to begin with, or if an initially strong signal is degraded in the subsequent electronic processing. The experienced operator can distinguish between these two possibilities by paying careful attention to the pictures displayed on the video monitors. When the system is operating properly, and the program is running, the KDP should produce a faint, but definite, "blinking" of fields on the live picture. This will not be so obvious on the main television monitor because the live pictures are interspersed with cancellations; however, it is quite obvious on the uninterrupted live picture displayed on a monitor plugged directly into the television camera. If this blinking is apparent, yet the cancellations are poor, the problem is in the electronic processing equipment; but if the blinking is not present to begin with, the problem is in the optical system preceding the camera.

Among the more common problems leading to a weak signal are:

a) Overcast sky:

If the light level is low enough that the live picture itself looks weak, washed-out, or noisy, the cancellations will, inevitably reflect this. If the light level seems low in spite of an apparently clear sky, one should visually verify that the various devices in the beam exhibit their proper transparancy. In particular, the KDP crystals show some tendency to develop a transparent brown haze on their electrode surfaces, especially if a DC current is allowed to flow through them for any significant length of time. To avoid such problems make sure that the program shuts off the KDP current between "runs".

A shift in the bandpass of the prefilter (due to aging) can also seriously degrade the image, although the fact that the prefilter is at fault will be apparent only after it has been examined on a spectrograph. The condition can sometimes be temporarily improved by altering the tilt of the prefilter, or, in extreme cases, by placing it in a separate heating oven.

b) KDP inoperative or voltage incorrect:

High-resistance separations at the KDP electrodes can result in an inadequate modulation of the polarization of the incoming sunlight. This condition is usually indicated by a failure of the KDP to draw its normal current (as shown by the meter on the high voltage power supply) during the modulation sequence. If this condition is suspected it may be verified either by placing the KDP between crossed polaroids and determining whether or not a source viewed through this combination modulates properly, or by comparing the signal obtained with the KDP against that obtained by mechanically rotating a mica quarter-wave plate in the solar beam.

Even with a properly operating KDP it is of course necessary to supply the correct (quarter-wave) voltage in order to obtain optimum results. In practice, this voltage can be easily determined by trial and error. Beginning with a moderate voltage of ~ 1 kV the KDP is rotated so as to optimize the magnetic signal (which may be quite weak).

Keeping the KDP at this angle the signal will go through a peak at some point between 0 and 5 kV. This is the optimum operating voltage.

c) Tilted filter:

If the birefringent filter is improperly aligned with respect to the beam, the spectral purity of its bandpass will be seriously degraded, again resulting in a weaker-than-necessary signal. Proper alignment is rather difficult to verify, but a fair approximation to it may always be achieved by removing the front window and prefilter, so that the surface of the first calcite element is exposed. The filter is then tilted so that the reflected beam goes straight back up the optic axis (as determined by holding a piece of paper with a hole in it as far as possible upstream).

The Doppler cancellations are more sensitive to misalignment than magnetograms, and the final adjustment, therefore, is usually made on the basis of them. If the tilt is incorrect, or if a bad part of the aperture is being used they will exhibit a strong gradient.

The KDP is also sensitive, as regards tilt, and must be lined up square to the beam for optimum performance. This, too, should be done on the basis of the quality of the cancellations, and not just according to the reflections off its surfaces, since the glass cover-plates may not be perfectly square to the crystal axis. When tilted at an extreme angle, or used in a too-rapidly-converging beam, the KDP will produce a ripple-like pattern in the otherwise featureless gray background of the magnetograms.

d) Filter temperature incorrect, KDP angle improperly adjusted:

The achievement of optimum signal strength requires careful attention to the filter tuning: both in adjusting the temperature so as to center the bandpass on the magnetically sensitive line, and in adjusting the angle of the KDP with respect to the calcite elements so as to obtain proper modulation of the input polarization.

A simple trial and error procedure will rapidly converge on these optimum settings:

1. While in the Zeeman mode, rotate the KDP until the strongest (proper polarity) signal is obtained.
2. Without changing the KDP angle, insert the circular polarizer and make a Doppler cancellation. If the cancellation is generally dark, increase the filter temperature. If it is generally light, decrease the filter temperature (assuming the usual white up, black down polarity convention).
3. When a satisfactory gray level has been achieved on the Doppler cancellations, remove the circular polarizer and go back to making magnetograms. If the temperature was changed in the previous step, a

slight readjustment of the KDP angle will be necessary in order to re-optimize the magnetic signal.

4. Repeat the process until the best Dopplergrams and magnetograms are obtained at the same settings of temperature and angle.

Note that adjustments in the filter temperature would be necessary even if the controller were perfectly stable (which it is not), since the shift in wavelength of the spectral lines (due to solar rotation) from one limb to the other is comparable with the line width. The settings which work well at Disk center are not particularly effective at either limb.

8. <u>Weak Cancellations</u>

Symptom:

If the live, modulated picture exhibits a healthy "blink", and yet the cancellations are still weak and noisy, then the problem is electronic. Common difficulties contributing to such problems include:

a) Noisy heads:

Noise introduced into the cancellations by faulty operation of the Read/Write heads on the Data Disc can range anywhere from a very subtle degradation of the pictures up to a complete wipe-out resembling the "push-pull" problem. If such difficulties are suspected, they can be best investigated by attempting to manually read and write frames on the individual heads. A problem in the recording process will usually result in a "frozen" noise pattern, while problems in playback are more generally represented by "moving noise" (the push-pull problem is an exception to this rule). Most often, the difficulty lies in the small circuit boards plugged into the sockets underneath the disc and to which the heads are connected by means of three-prong transistor sockets. Troubleshooting there is greatly simplified by the fact that there are four identical cards -- one for each head -- which can be freely interchanged (the cards can be removed and reinserted while the Disc is running, but be careful not to plug them in upside down). By attempting to record and play back on each head and through each of the cards, the problem can usually be assigned either to a specific head or to a specific card. If the problem is in the cards, it is usually either a faulty transistor or a blown fuse (a tiny 1/8-A fuse, which looks something like a diode, is wired in series with the recording head, and will blow if the Disc is left in the WRITE mode for more than a second or two).

Cleaning the disc (with alcohol and xylene) will, on very rare occasions, cure problems associated with the heads; but, more often than not, if the problem has to do with the heads themselves it will involve actual physical damage to the ferrite chip, and be reparable only by replacing the faulty head. Cleaning of the disc, although recommended in the operator's manual, is probably to be discouraged because the possibility of causing new damage exceeds the probability of achieving any noticeable improvement.

b) Data Disc improperly "balanced":

The Data Disc contains a very large number of variable resistors which control the gain and DC level of the video signals at various stages in the Disc's modulation and demodulation circuitry. The most important of these is the infamous "DC-level pot" which has been described elsewhere, and whose proper adjustment is necessary in order to insure that pictures are faithfully <u>recorded</u>, and that they do not shift towards a saturated black or white as they are re-recorded during the averaging process.

It is equally important that the two fixed heads be played back with nearly matched gains so that the multiplexer can form a decent cancellation. This balancing can be achieved either by recording a known signal and carefully studying the result, as played back by the two heads (using the oscilliscope), or, equally well, by trial-and-error, turning various pots at random to see whether the signal is improved or not (if no change is seen be sure to return the pot to its original setting). If the sun is not available, or its use inconvenient for this purpose, a good calibration source can be constructed by sandwiching the KDP between partially crossed polaroids, and viewing a relatively weak light source through the combination (with the TV camera). The KDP will modulate this artificial source just as if it were a real one, and the Disc should therefore be adjusted so as to optimize this "signal".

Trying to tweak up the system on the basis of "self-cancellations" (with no modulated light source) is definitely not recommended. It is very easy to be deceived, and to adjust things so that no amount of signal will produce anything but a blank gray screen.

c) "N-knob" set too low:

This condition has already been described. The live picture and initial cancellations will look OK, but the contrast will decrease on each repetition of the averaging sequence, until the final cancellation looks as if it had been produced from a weak signal.

9. <u>Program Errors</u>

Cause:

The majority of problems encountered in the use of the program are the result of accidentally starting the program at the wrong address. Often this will alter the contents of some location in the computer memory where the program itself is stored. Usually this will not be immediately disastrous but an accumulation of such effects will rapidly cause the program to become inoperative.

Cure:

Reload the program. If this does not work, try clearing the entire core, and reloading the program again. Instructions for doing this will be found with the computer.

If the program starts OK, but then stops after homing the heads, the problem could be that the computer is failing to see the "once-around" clock from the Disc. The program will "WAIT" until it sees such a clock pulse before executing any step connected with recording or processing the video frames.

10. <u>Gray Areas Around the Edges</u>

Cause:

The live picture is shifted over horizontally with respect to the magnetograms by the sync-compensation circuitry. Gray areas around the edges on the final cancellation may result from the presence of a field stop which is just barely outside the field of view on the live picture. The field stop is round and about 50% larger than the size of the field of view.

Cure:

Readjust the position of the field stop.

11. <u>Linear Smearing of Magnetic Features</u>

Cause:

Some of the magnetograms exhibit a pronounced horizontal smearing of the magnetic features. One cause of this effect is systematic errors in the telescope guiding during the course of the integration. This is particularly prominent when the telescope is on "tracking" and following the sun at a slightly incorrect rate, as was frequently the case during the daily surveys.

Cure:

Use guiding whenever possible.

12. <u>Magnetic Leakage</u>

Symptom:

In any magnetograph fed by a system of mirrors there will be significant magnetic "cross-talk" introduced into Doppler cancellations made with a magnetically sensitive line, as has been explained elsewhere.

Cure:

In practice the cross-talk can be virtually eliminated by a suitable angular orientation of the circular polarizer in the beam. The exact orientation of the polarizer which achieves this result will have to be determined by trial and error. If the live modulated image, direct from the camera is viewed on a TV monitor while the polarizer is being rotated, a marked change in the "character" of the signal will be noted for various orientations.

13. <u>Miscellaneous Problems With the Camera Controller</u>

The quality of the live video images is dependent, to a large extent, on having the controller properly adjusted. Hence, it is necessary for the operator to be familiar with the function of each of the control knobs, some of the most important of which will be described here:

<u>Front Panel Controls</u>:

1. <u>Beam</u>: This adjusts the current used to discharge the camera's photocathode. If the setting is too low, the faceplate will charge up permanently, and the picture will saturate. Advancing the control will cause the live picture to re-appear. Recovery takes a couple of seconds, and is marked by an appearance like water or molasses rolling off the screen. The proper setting is just above this point. Excessive beam current will unnecessarily shorten the life of the tube.

2. <u>Gain</u>: The front panel gain control affects the picture only when the AUTO/MANUAL switch is in the MANUAL position. In that mode, it adjusts the degree to which the signal is amplified. Since the maximum video voltage is about 1 V., and excessive gain will cause the highlights to saturate (electronically). In the AUTOMATIC mode, the gain is determined as described in Item 5.

3. Black-level: The black-level control adjusts the signal level corresponding to the darkest feature in the live picture. The magnetograph often seems to work best with a rather low contrast live image.

4. Focus: The front panel FOCUS control affects only the sharpness of the electronic imaging. A good live image requires both a correct optical focus (on the faceplate) and a correct electronic focus.

5. POS/NEG switch: The Plumbicon controller is capable of producing an inverted output signal if one wishes to have negative images appear on the monitor.

6. Gamma & Target: These controls are for Vidicon tubes (which can be used with the same controller), and should not affect the performance of the Plumbicon.

If the front panel is swung down (by releasing the screws at the corners), a second series of controls (mainly screw-driver adjustable pots) will be revealed. Most of these are of little consequence, causing only minor modifications in the linearity of response. The others are described here:

Internal Controls:

1. H & V: The controls on this panel affect the size and shape of the area scanned on the photocathode, and are thus similar in action to the horizontal and vertical controls on a video monitor. Underscanning can allow one to develop

enough beam current to discharge an image (such as an outdoor scene) which would otherwise be too intense, but it also causes the tube to age non-uniformly. Overscanning causes the image to appear like a round button on the screen.

2. Peak-to-Peak/Average: This selects the mode to be used by the Automatic Gain Control, as described in Item 5.

3. Cable length: This has to be adjusted in conjunction with the length of cable used between the camera head and the controller. Improper termination introduces a snow-like background noise pattern.

4. Line Rate: The switch should be set for 60 Hz/525 lines.

Finally, a number of controls are located on the rear of the controller chassis:

1. Disc/Int switch: This is used when the camera is slaved off the Disc (as is usually the case). Don't leave the camera in this mode unless the Disc is running and putting out a clock track; otherwise the beam may burn a hole in the faceplate. The only exception is when a new clock track is being written.

2. Int/Ext switch: This is not normally used. The Plumbicon can be slaved off a second controller if one steals the four sync signals. It would be used in the "two camera" mode.

3. BNC connectors:

   a. H,V,B, & S: These stand for horizontal, vertical, blanking, and sync. Four of the terminals are inputs (to be used when the controller is slaved off a second), and four are outputs (to be used when the controller acts as the master). All unused terminals should be terminated with 75Ω resistors.

b. VBS(1)&(2): These are the two main video outputs. The signal is in a "composite" form, and can drive a monitor directly. Normally, however, a more stable display can be obtained by patching the controller's S-output to the External Sync input on the monitor.

c. Monitor: One can route signals for display be a separate monitor at the camera head.

4. The Black Wire: A black wire dangling out the back of the controller taps the internally-generated sync signal, which must be copied to write a new clock track. A small external transistor amplifier acts as a buffer between the two circuits.

14. Flicker and Shading in the Monitor Display

Symptom: The final cancellation displayed on the monitor often displays both a severe 30-cycle flicker and a prominent shading of background intensity from top-to-bottom. Both the shading and the flicker are caused by a "ramp" which develops in the recorded signal as a result of repeated writing and playback. The ramp is evident if the signal is examined on the oscilliscope. The zero level normally increases throughout the scan, and the second of the two interlaced frames is substantially brighter than the first.

Cure: The ramp can be eliminated by using the compensator circuit in the narrow panel above the computer. The compensator uses a 60-cycle clock which may or may not be properly synced to the 30-cycle frame rate. A toggle switch in the center determines this. In one position, turning the compensator control knobs makes the picture better, in the other it makes it worse. Sometimes it is not possible to suppress both the flicker and the gradient at the same time. Emphasis should be placed on the gradient since it will show up on the final photograph whereas the flicker will not. The setting of the toggle switch may have to be changed from time to time. Placing it in the middle position will take the compensator out of the circuit entirely.

15. Problems with filter temperature controller:

If, due to an electronic malfunction, the controller supplies a continuous high current to the filter heating coil, the filter elements can be seriously damaged by overheating. A "fail-safe" device in the coil is supposed to interrupt the circuit if the temperature rises above 50° C., but it is not entirely obvious that it works. The operator should, therefore, keep an eye on the current, as indicated by the ammeter on the controller front panel. When properly operating it will usually hover at $\sim 1/3$ full scale with small, rapid fluctuations.

The ammeter on the KDP power supply should also be watched. If the KDP draws a continuous current, even a small one, something is wrong and damage will result.

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